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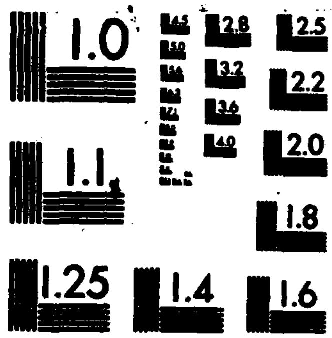

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TECHNICAL INFORMATION BULLETIN
83-6

GROUP 4 FACSIMILE THROUGHPUT ANALYSIS

SEPTEMBER 1983

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The purpose of this effort is to project the near term characteristics of public data networks and Group 4 facsimile systems, and estimate the efficiency with which Group 4 messages will be transmitted over various types of data networks (e.g. packed switched, circuit switched, and the public switched telephone network.) Characteristics of packed switched, circuit switched, and public switched networks were analyzed and projected. The present status of Group 4 facsimile and its technical characteristics in the near term were analyzed and projected. Hypothetical networks were (cont'd)

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constructed consisting of the projected characteristics of Group 4 facsimile equipment transmitting over the three different types of baseline data networks (e.g. packet switched, circuit switched, and the ~~PSTN)~~. The efficiency with which the facsimile data was handled by these representative networks was also estimated.

Public Switched Telephone Network.

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NCS TECHNICAL INFORMATION BULLETIN 83-6

GROUP 4 FACSIMILE THROUGHPUT STUDY ANALYSIS

SEPTEMBER 1983

PROJECT OFFICER

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Office of NCS Technology
and Standards

APPROVED FOR PUBLICATION:

Edward P. Greene

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Acting Assistant Manager
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FOREWORD

Among the responsibilities assigned to the Office of the Manager, National Communications System, is the management of the Federal Telecommunication Standards Program. Under this program, the NCS, with the assistance of the Federal Telecommunication Standards Committee identifies, develops, and coordinates proposed Federal Standards which either contribute to the interoperability of functionally similar Federal telecommunication systems or to the achievement of a compatible and efficient interface between computer and telecommunication systems. In developing and coordinating these standards, a considerable amount of effort is expended in initiating and pursuing joint standards development efforts with appropriate technical committees of the Electronic Industries Association, the American National Standards institute, the International Organization for Standardization, and the International Telegraph and Telephone Consultative Committee of the International Telecommunication Union. This Technical Information Bulletin presents an overview of an effort which is contributing to the development of compatible Federal, national, and international standards in the area of digital facsimile standards. It has been prepared to inform interested Federal activities of the progress of these efforts. Any comments, inputs or statements of requirements which could assist in the advancement of this work are welcome and should be addressed to:

Office of the Manager
National Communications Systems
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Washington, DC 20305
(202) 692-2124

GROUP 4 FACSIMILE

THROUGHPUT

STUDY ANALYSIS

Final Report

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310 Cottman Street

Jenkintown, Pennsylvania 19046

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APPENDICIES

1.0 INTRODUCTION

This document summarizes work performed by Delta Information Systems, Inc. for the office of Technology and Standards of the National Communications System, an organization of the U.S. Government, under contract number DCA100-82-C-0072. The Office of Technology and Standards, headed by National Communications System Assistant Manager Marshall L. Cain, is responsible for the management of the Federal Telecommunications Standards Program, which develops telecommunication standards whose use is mandatory by all Federal agencies.

A very active on-going standardization endeavor is the development of Federal Standards relating to digital facsimile. Federal Standards 1062 and 1063 pertaining to Group 3 facsimile equipment have recently been promulgated. Standards for Group 4 facsimile transmission over Public Data Networks (PDN) are now under development. Some PDN's (e.g., packet switching) have been designed primarily for the communication of short bursty messages (typically 1,000 - 2,000 bits per message) between computers and data terminals. The typical length of a Group 4 facsimile message is forecast to be very long - typically 500,000 (compressed data) bits per message. There is serious concern that PDN's of this type may not handle facsimile traffic very efficiently.

The purpose of this study is to project the near term characteristics of public data networks and Group 4 facsimile systems, and estimate the efficiency with which Group 4 messages

will be transmitted over various types of data networks (e.g. packet switched, circuit switched, and the public switched telephone network.)

Work on this contract was divided into the three tasks which are listed below.

Task 1 Data Network Analysis/Projection

The characteristics of the following three types of data networks were analyzed and projected.

- Packet switched networks (e.g. Telenet, Tyment)
- Circuit switched data networks (e.g., Circuit Switched Data Capability)
- Public Switched Telephone Network

Task 2-Group 4 Facsimile Analysis/Projection

The present status of Group 4 facsimile and its technical characteristics in the near term were analyzed and projected. The following parameters were examined.

- Modes of operation
- Communication protocol
- Coding and compression
- Group 4 terminal structure

Task 3 - Throughput Analysis

Hypothetical networks were constructed consisting of the projected characteristics of Group 4 facsimile equipment transmitting over the three different types of baseline data networks (e.g., packet switched, circuit switched, and PSTN). The efficiency with which the facsimile data is handled by the

representative data networks has been estimated.

The work performed on the three tasks listed above is described in sections 2.0, 3.0, and 4.0 respectively. Section 5.0 contains summary and concluding remarks.

2.0 Task 1 - Data Network Analysis/Projection

The purpose of task 1 is to "analyze and project the characteristics of the following three types of communication networks".

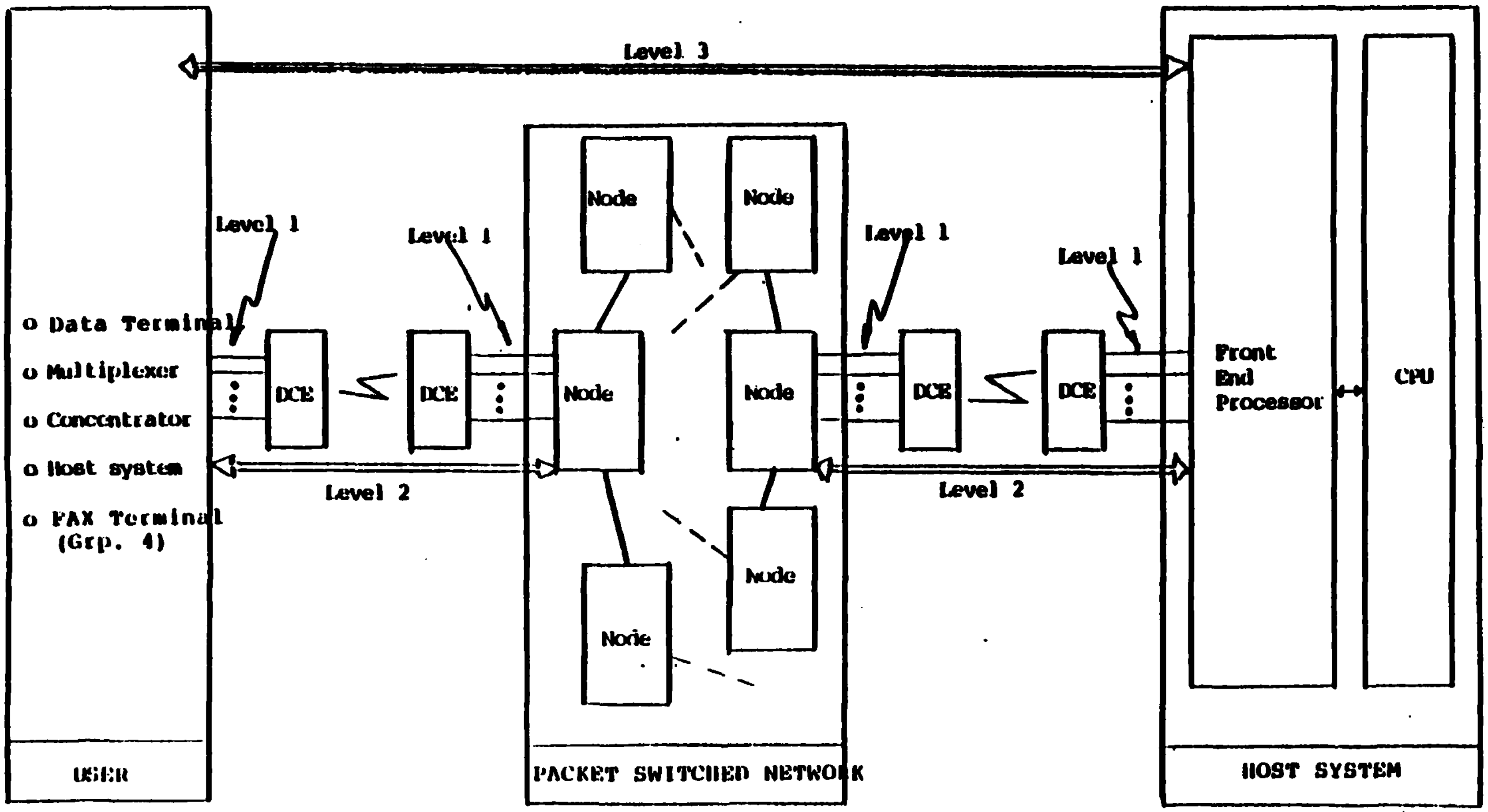
- Packet switched data network (PSDN)
- Circuit switched data network (CSDN)
- Public switched telephone network (PSTN)

Each of these networks is separately discussed in the following sections.

2.1 Packet Switched Data Networks (PSDN)

The CCITT has developed recommendation x.25 to define the "interface between data terminal equipment (DTE) and data circuit terminating equipment (DCE) for terminals operating in the packet mode on public data networks." The x.25 recommendation specifies OSI layers 1, 2, and 3 for transmission over Packet Switched Data Networks (PSDN). Figure 2-1 illustrates the three functional levels of the x.25 recommendation. Figure 2-2 is a list of the large number of packet switched data networks which are operational around the world.

During the course of this task many phone conversations and trips were held with personnel associated with packet switched data networks. Based upon these communications the parameters of a baseline PSDN are listed in Table 2-1. The only parameter in this table which may require clarification is the term



Level 1- Physical; RS232C, RS449, X.21
Level 2- Link Access Procedure; HDLC LAPB
Level 3- Network; X.25

Figure 2-1

BLOCK DIAGRAM ILLUSTRATING ARCHITECTURAL LEVELS OF THE

X.25 INTERFACE STANDARD

Figure 2-2

INTERNATIONAL DESTINATIONS AND TARIFFS

COUNTRY	NETWORK(S)	TARIFFS Duration (per minute) ①	Volume (per 10 segments)‡ ②
* Australia	Austpac	Not yet available	
* Australia	Midas	Not yet available	
* Austria	Radio Austria	Not yet available	
Belgium	Euronet	2.2p	1.2p
* Belgium	DCS	Not yet available	
Canada	Datapac	8p	3p
Canada	Globedat	8p	3p
Canada	Infoswitch	8p	3p
Denmark	Euronet	2.2p	1.2p
Federal Republic of Germany	Datex-P	2.2p	1.2p
Federal Republic of Germany	Euronet	2.2p	1.2p
Finland	Finnpak	2.2p	1.2p
France	Transpac	2.2p	1.2p
French Antilles		10.0p	4.0p
* Hong Kong	IDAS	Not yet available	
Irish Republic	Euronet	2.2p	1.2p
Italy	Euronet	2.2p	1.2p
Japan	Venus-P	10.0p	4.0p
Japan	DDX-P	10.0p	4.0p
Luxembourg	Euronet	2.2p	1.2p
Netherlands	Euronet	2.2p	1.2p
* Netherlands	Datanet 1	Not yet available	
* New Zealand	Oasis	Not yet available	
* Norway	Norpak	Not yet available	
Portugal		2.2p	1.2p
Singapore	Telepac	10.0p	4.0p
* South Africa	Saponet	Not yet available	
Spain	NTID	2.2p	1.2p
Sweden	Telepak	2.2p	1.2p
Switzerland	Data-Link	2.2p	1.2p
Switzerland	Euronet	2.2p	1.2p
* Switzerland	Telepac	Not yet available	
USA	ITT-UDTS	8p	3p
USA	RCA-LSDS	8p	3p
USA	Telenet	8p	3p
USA	Tymnet	8p	3p
USA	WUI-DBS	8p	3p

Although correct at the date this booklet went to press, the information given is subject to revision and services may be modified, added to or withdrawn, without individual notice to subscribers.

① Or part of a minute
② Or part of 10 segments
‡ See notes overleaf
* See notes overleaf

Data calls to the U.K. can also be made from:

Australia, Bahrain, Barbados, Bermuda, *Dubai, Hong Kong, Israel, Japan (ICAS), New Zealand

Table 2-1

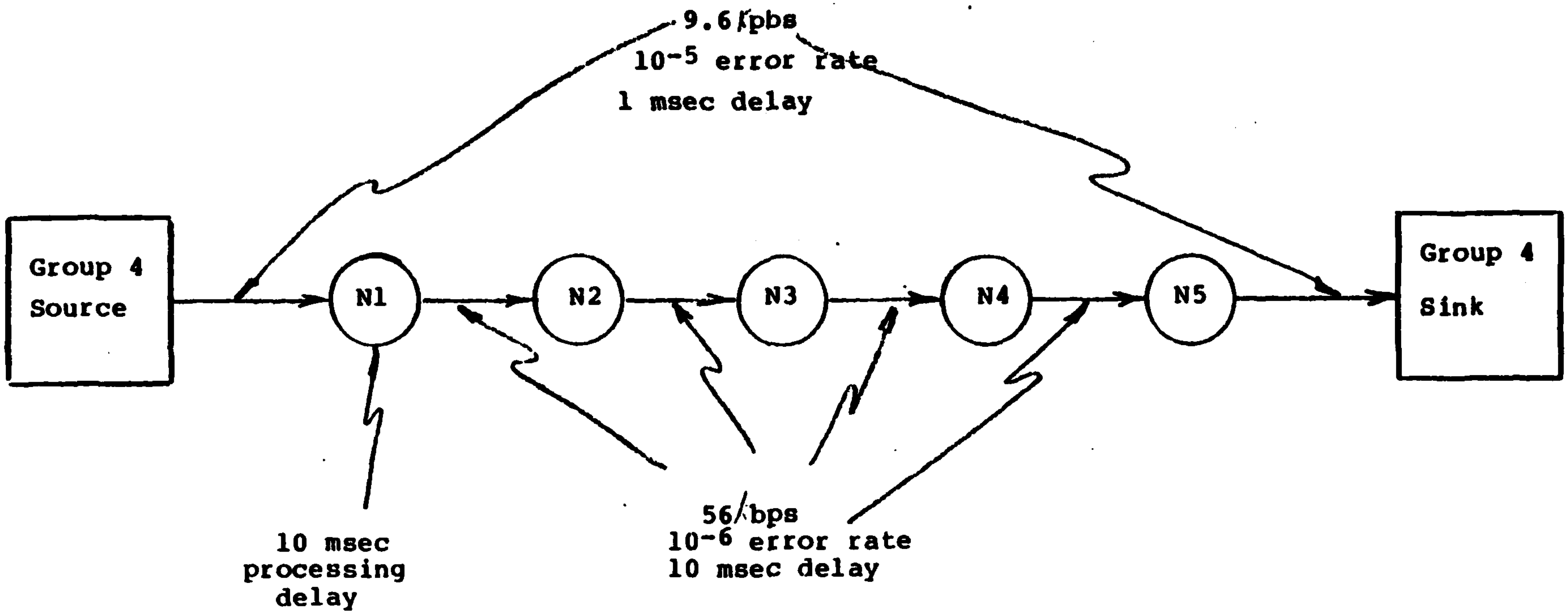
Assumptions for the BASELINE Packet Switched Data Network

Parameter	Baseline Value
Length of facsimile message-btis	500,000
Local signalling rate - bits/sec	9,600
Network signalling rate - bits/sec	56,000
Local error rate	10^{-5}
Network error rate	10^{-6}
Local Propagation Delay - msec	1
Network Propagation Delay - msec	10
Processing Delay - msec	10
Number of nodes	5
Network Loading	.8
Packet Size - bytes Corresponding network window	128
Transport Block Size - bytes	512
Network Window	6

"network window". This parameter refers to the maximum number of packets which may be transmitted into the PSDN at any time which are not acknowledged. Figure 2-3 is a functional block diagram of the baseline PSDN.

Figure 2-3

BASELINE PACKET SWITCHED DATA NETWORK



2.2 Circuit Switched Data Network (CSDN)

AT&T is in the process of introducing a new CSDN which is called the "Circuit Swtiched Digital Capability" (CSDC). Although not presently offered, a development effort is well under way and a significant portion of CSDC relies on existing facilities. Information obtained to date, indicates CSDC will be available on a limited basis in early 1984. It is particularly pertinent to consider the CSDC for Group 4 facsimile because the transmission bit rate is 56 KPS. This bit rate will permit a typical page to be transmitted in approximately 9 seconds. This page rate will make it possible for users to interchange pages in real time.

CSDC will provide end-to-end full-duplex, 56 Kb/s, circuit-switched, synchronous data over much of the existing Bell System Network. Figure 2-4 illustrates the CSDC. The system relies on 2-wire local loop. The leading candidate approach is to time-share the 2-wire path using rates slightly greater than 2 x 56 Kb/s.

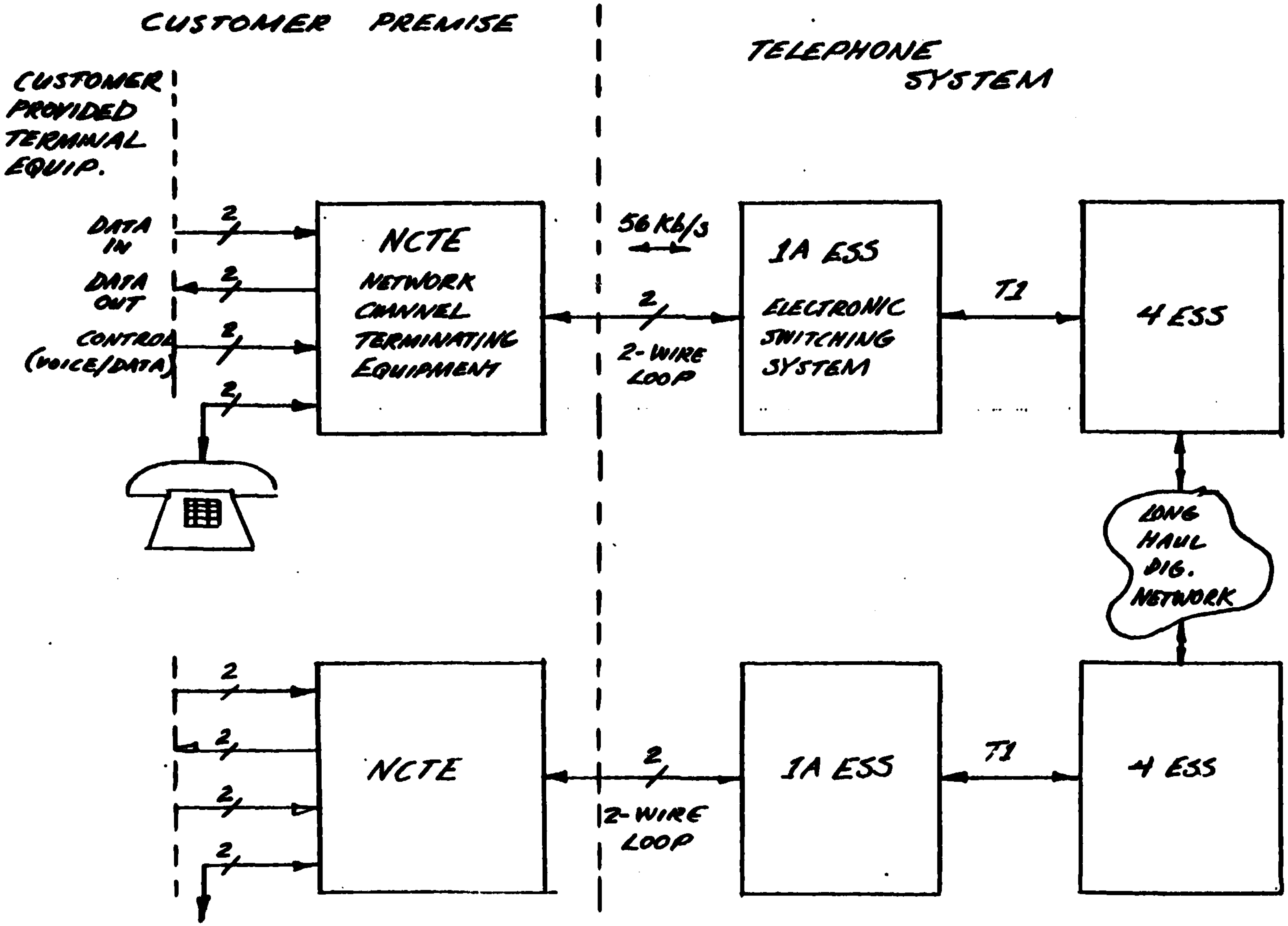
Following is a listing of features for the CSDC.

Type Service: Alternate voice/data modes

Data Rate: 56 Kb/s (other rates may be available-9600 b/s initially)

Call Setup Procedure: Via Touch-Tone, a user dials a special access code followed by the 7 (or 10) digit number of the called party.

Local Loop: Present plan calls for removal of loading coils plus some loop conditioning. Should permit operation to 18,000 ft.



AT&T's CIRCUIT SWITCHED DIGITAL CAPABILITY (CSDC)

Figure 2-4

Loop Signal: Two schemes are proposed: The leading candidate is a time multiplexed (TM) or burst mode at slightly higher than 112 Kb/s. The second or hybrid scheme is full duplex separation. Both approaches use bypolar AMI type signals.

Timing: The service will be synchronous. Timing is according to the DDS nationwide synchronization system.

Signaling (2-wire): Conventional on/off-hook via open/closure. Voice/data is via normal/reverse battery.

Error Performance: Simulation results indicate a BER of 10^{-7} for 60% of the data/time; 10^{-6} for 95% of the data/time.

2.3 Public Switched Telephone Network (PSTN)

The primary advantage of the PSTN over other networks is that it is universally available virtually everywhere. The disadvantage is that it is designed to handle voice, not digital data. This restricts the rate at which facsimile digital data can be reliably transmitted.

It is likely that if Group 4 facsimile terminals transmit over the PSTN they will use the same standard CCITT modems which have been used so successfully in Group 3. The key characteristics of these modems are summarized in Table 2-2.

The reader will note from the V.29 title that the CCITT indicates the V.29 modem is to be used over "leased telephone-type circuits". Nevertheless most Group 3 facsimile systems contain the V.29 modem, and it is used quite successfully over the PSTN. It is used with less success over the European PSTN's because the quality of the European PSTN's are of a slightly reduced quality relative to those in the United States.

There are two parameters of the PSTN which are critical determinants of the throughput for Group 4 facsimile - bit rate and bit error rate. As indicated above it is very difficult to accurately characterize the PSTN for these two parameters. The performance of the PSTN varies over a wide range as a function of the following parameters.

- Country: the performance of the PSTN in the U.S. is typically superior to that in Europe.
- Location within country: the performance of the PSTN in certain regions of the U.S is superior to that in other regions.

Table 2-2

Standard CCITT Modems used for the PSTN

CCITT Recommendation No.	V.27 ter	v.29
CCITT Recommendation Title	4800/2400 bits per second modem standardized for use in the general switched telephone network	9600 bits per second modem standardized for use on point-to-point 4 wire leased telephone-type circuits
Modulation Technique	4800bps- 8 phase DPSK 2400bps- 4 phase DPSK	9600 bps; Combination of 8 phase DPSK and two level AM 7200 bps; Fallback; 8 phase DPSK
Carrier Freq.	1800 Hz	1700 Hz
Scrambler	No	Yes

- Distance: the performance for short local calls is typically superior to that over longer distances
- Modem vendor: some modems perform better than others.

Based on the uncertainty of the above parameters the PSTN Group 4 throughput analysis is best performed on a parametric basis with the following range of parameters.

Bit rate - 9600 bps

Bit error rate - 10^{-4}, 10^{-5}, 10^{-6}

3.0 Task 2 - Group 4 Facsimile Analysis/Projection

The objective of task 2 is to "analyze the present status of Group 4 facsimile development and project its technical characteristics in the near term". The work performed on this task was divided into the four parts listed below and discussed in Sections 3.1 through 3.4.

- Modes of operation
- Communication protocol
- Coding and compression
- Group 4 terminal structure

3.1 Modes of Operation

The CCITT has developed draft recommendation T.a entitled "Apparatus for Use in the Group 4 Facsimile Service." A copy of this recommendation is included in Appendix A. This document defines three classes of Group 4 service which are summarized in Figure 3-1. This table shows that classes 2 and 3 are required to provide a TELETEX and Mixed Mode service as well as basic facsimile service. For purposes of this study the only service which will be considered is the conventional facsimile service as defined in Class 1 in addition to the facsimile service in modes 2 and 3.

Figure 3-1 also shows that all Group 4 facsimile equipments must be able to transmit at 200 pels/inch in both the horizontal and vertical direction. Class 2 and 3 equipment must also be able to transmit/receive at 300 pels/inch. Additional transmission options are 240 and 400 pels/inch.

SERVICE \ CLASS		1	2	3
SERVICE	FACSIMILE	SEND/RECEIVE	SEND/RECEIVE	SEND/RECEIVE
	TELETEX	-	RECEIVE	GENERATE/ TRANSMIT/ RECEIVE
	MIXED MODE	-	RECEIVE	GENERATE/ TRANSMIT/ RECEIVE
TRANSMIT RESOLUTION	STANDARD	200	200 and 300	200 and 300
	OPTIONAL	240,300,400	240,400	240,400
PEL CONVERSION		NOT REQUIRED	YES	YES
PAGE MEMORY		NOT REQUIRED	YES	YES

CLASSES OF GROUP 4 TERMINALS

FIGURE 3-1

3.2 Communication Protocol

The CCITT has determined that the 7 layer OSI (Open System Interconnect) protocol which has been developed by the ISO (International Standards Organization) will be used for Group 4 facsimile. Figure 3-2 is a tabulation of the seven layers along with the designation of each layer, the applicable Group 4 CCITT recommendation, and a description of the function of each layer.

As shown in Figure 3-2 the CCITT has established recommendation S.70 entitled. "Network-Independent Basic Transport Service for Teletex" for Group 4 facsimile layer number 4. As indicated by the title of the recommendation this standard is applied to both Teletex (communicating word processors) and Group 4 facsimile. Recommendation S.70 outlines the protocol for G4 fax transmission over the three different communication networks listed below.

- Packet switched data networks (PSDN)
- Circuit switched data networks (CSDN)
- Public switched telephone network (PSTN)

Figure 3-3 is taken from S.70 and shows the different CCITT recommendations which exist for levels 1, 2 and 3 for the three different communication networks. Note that levels 1 through 4 consist of protocols which insure reliable communication between two users over any network or multi-network configuration. Protocol levels 5, 6, and 7 are concerned with the data itself and are independent of the communication process at the lower levels.

Figure 3-4 illustrates the top 4 OSI levels emphasizing the

Figure 3-2

OSI COMMUNICATIONS PROTOCOL FOR GROUP 4 FACSIMILE

OSI LAYER NO.	LAYER NAME	APPLICABLE GROUP 4 CCITT RECOMMEN-DATION	FUNCTION
7	APPLICATION	T.a.	User Application Process; Defines a specific application; text editing, payroll processing, electronic mail, information retrieval; What the user is aware of; T.a. defines parameters of scanner/reorder.
6	PRESENTATION	T.b,S.a	Data interpretation, format, code transformation; Peripheral device coding; character set translation; information formatting- modification of data layout, page rotation, B4/A4; encryption: T.b defines coding technique: S.a defines mixed mode protocol.
5	SESSION	S.62	Logical linking of user processes; who talks first, time, date, subscriber number; broadcast control.
4	TRANSPORT	S.70	Assures end-to-end data integrity and provides for the required quality of service for exchanged information; synchronization, control, multi-plexing, reestablishment under error conditions.
3	NETWORK	X.25	Controls the addressing, switching, and routing of the information to establish a virtual circuit connection; defines packet formats and control procedures; flow control.
2	LINK	HDLC LAPB	The link access procedure for reliable data interchange across the link between the DTE and the data network; error handling; flow control; e.g. "rcvr ready", "rcvr not ready"; establish, maintain, and release data links.
1	PHYSICAL	X.21 RS449 RS232	The physical, electrical, functional,, and procedural characteristics to establish, maintain, and disconnect the physical link between the DTE and the network.

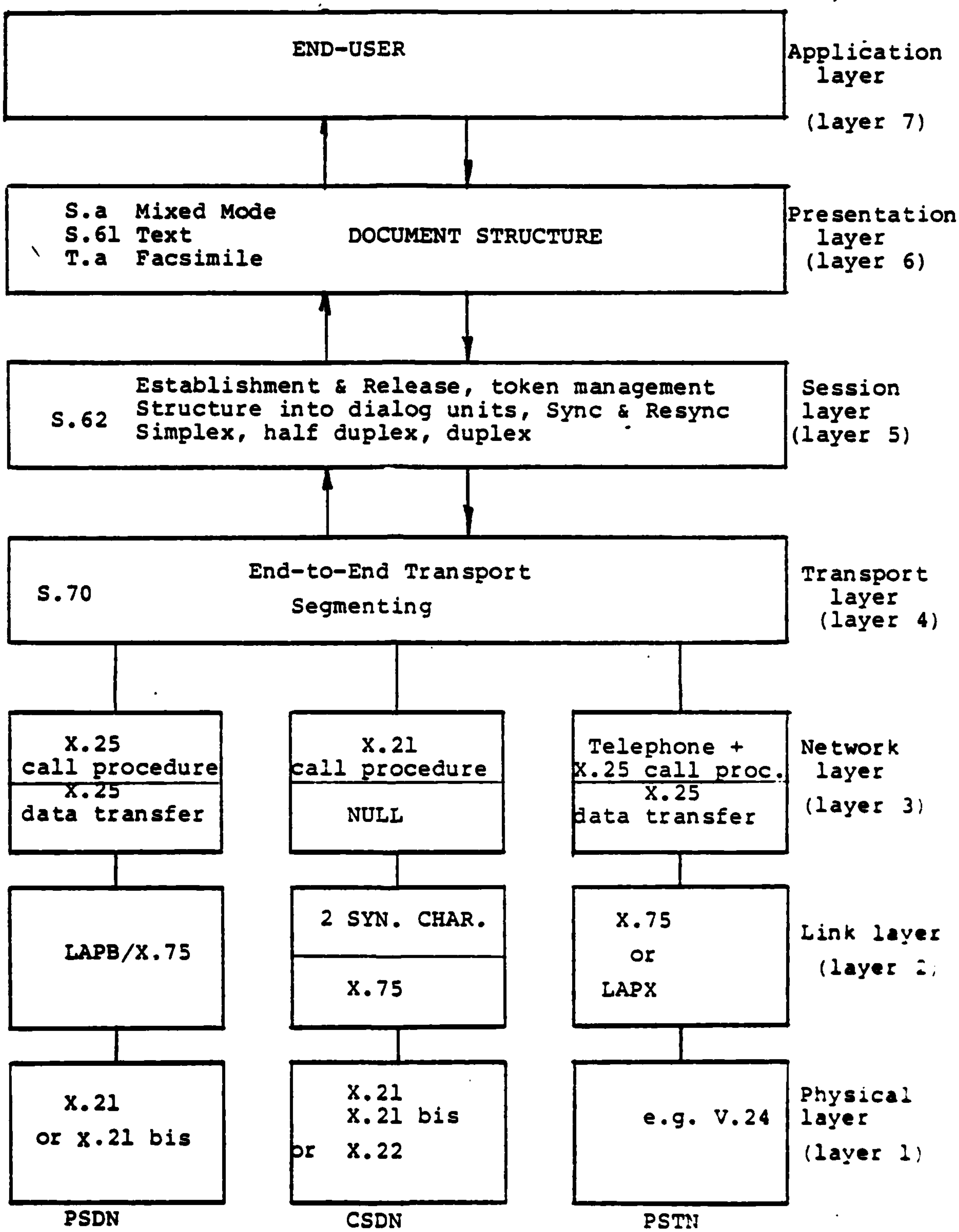
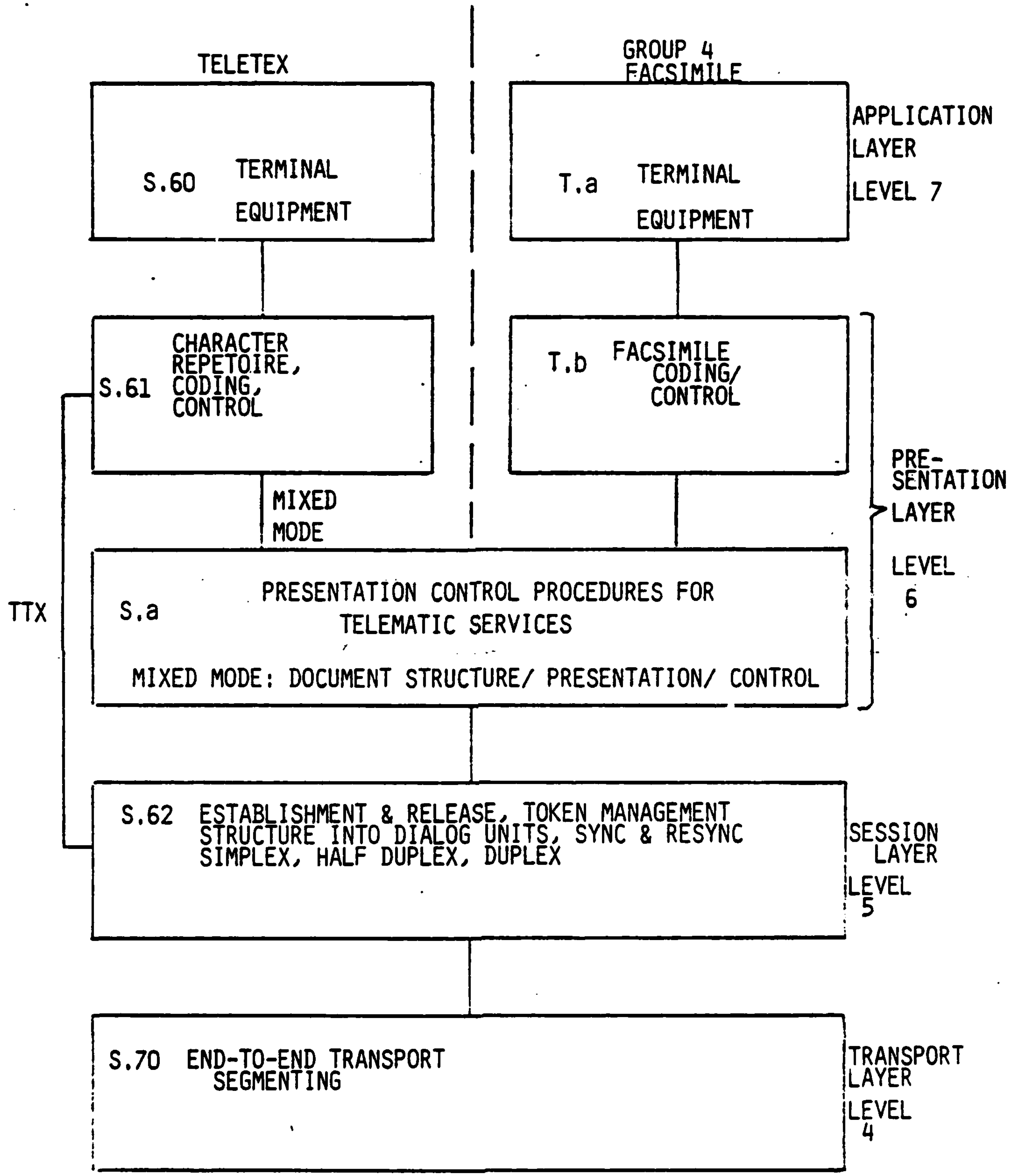


Figure 3-3 Group 4 FAX Protocol Structure



FRAMEWORK OF CCITT RECOMMENDATIONS
FOR GROUP 4 FACSIMILE APPARATUS

FIGURE 3-4

relationship between the Teletex and Group 4 services. Note that S.a is the key recommendation for mixed mode operation, and this standard has not yet been finalized.

3.3 Coding and Compression

As explained above the CCITT has developed Recommendation T.b, entitled "Facsimile Coding Schemes and Coding Control Functions for Group 4 Apparatus" to implement a portion of the OSI layer 6 functions (see Figure 3-4). Recommendation T.b is included in Appendix B. This recommendation specifies the compression algorithm to be used for Group 4 facsimile. The G4 algorithm is an extension of the Modified READ Code (MRC) which is the optional code for Group 3 facsimile. We will define the Group 4 coding technique to be the Extended Modified READ Code (EMRC). The essential differences between the G3 Modified READ code (MRC) and the EMRC are summarized below.

CODING TECHNIQUE / Parameter	G3 MRC	G4 EMRC
K-Factor	K=2 (std. res) K=4 (high res)	K= ∞
Line Synchronization Code Word	EOL Code + Tag	None
Fill bits per line	Variable length string of "o"s	None

Delta Information Systems performed a contract for the U.S. Government (Contract DCA100-81-C-0042) to measure the compression ratio for the EMRC algorithm. The compression was measured for standard CCITT documents numbered 1, 5, and 7 (see Figure 3-5, 3-6, and 3-7 respectively). The 3 documents were scanned at five resolutions (200, 240, 300 400, 480 pels/inch) and the EMRC compression was measured for the 3 documents at the 5 resolutions. The compressed bits/page are summarized in Table 3-1. Figure 3-8 shows this same data where the compressed bits are plotted as a function of resolution. Figure 3-9 shows this same data where the compresssion ratio is plotted as a function of resolution.

One of the most important questions to be answered before a meaningful throughput analysis can be performed is "How many bits will there be in the typical G4 facsimile message?" To answer this question the reader is referred to Figure 3-8.

It is assumed that 300 pels/inch is a representative resolution for Group 4 facsimile since it splits the extremes of 200 and 400 pels/inch. Since the number of bits/page for the average of the three documents is approximately 500,000 bits this figure was selected to represent the typical G4 fax message.

THE SLEREXE COMPANY LIMITED

SAPORS LANE - BOOLE - DORSET - BH 25 8 ER

TELEPHONE BOOLE (945 13) 51617 - TELEX 123456

Our Ref. 350/PJC/EAC 18th January, 1972.

Dr. P.N. Cundall,
Mining Surveys Ltd.,
Holroyd Road,
Reading,
Berks.

Dear Pete,

Permit me to introduce you to the facility of facsimile transmission.

In facsimile a photocell is caused to perform a raster scan over the subject copy. The variations of print density on the document cause the photocell to generate an *analogous* electrical video signal. This signal is used to modulate a carrier, which is transmitted to a remote destination over a radio or cable communications link.

At the remote terminal, demodulation reconstructs the video signal, which is used to modulate the density of print produced by a printing device. This device is scanning in a raster scan synchronised with that at the transmitting terminal. As a result, a facsimile copy of the subject document is produced.

Probably you have uses for this facility in your organisation.

Yours sincerely,

Phil.

P.J. CROSS
Group Leader - Facsimile Research

Figure 3-5 CCITT Document No. 1

Cela est d'autant plus valable que $T\Delta f$ est plus grand. A cet égard la figure 2 représente la vraie courbe donnant $|\phi(f)|$ en fonction de f pour les valeurs numériques indiquées page précédente.

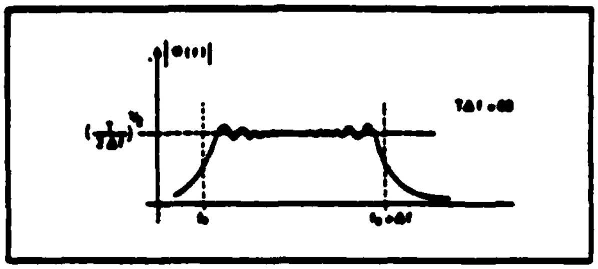


FIG. 2

Dans ce cas, le filtre adapté pourra être constitué, conformément à la figure 3, par la cascade :

— d'un filtre passe-bande de transfert unité pour $f_0 \leq f \leq f_0+\Delta f$ et de transfert quasi nul pour $f < f_0$ et $f > f_0+\Delta f$, filtre ne modifiant pas la phase des composants le traversant ;

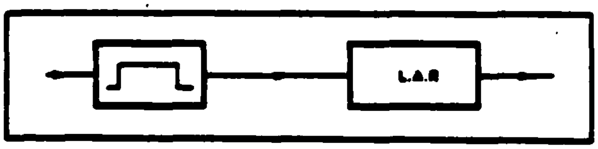


FIG. 3

— filtre suivi d'une ligne à retard (LAR) dispersive ayant un temps de propagation de groupe T_R décroissant linéairement avec la fréquence f suivant l'expression :

$$T_R = T_0+(f_0-f)\,\frac{T}{\Delta f} \quad (\text{avec } T_0 > T)$$

(voir fig. 4).

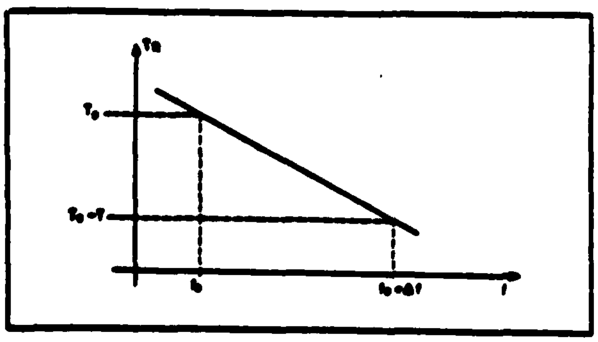


FIG. 4

telle ligne à retard est donnée par :

$$\varphi = -2\pi \int_0^f T_R \, df$$

$$\varphi = -2\pi \left[T_0+\frac{f_0 T}{\Delta f}\right] f + \pi\,\frac{T}{\Delta f}\,f^2$$

Et cette phase est bien l'opposé de $\underline{/\phi(f)}$, à un déphasage constant près (sans importance) et à un retard T_0 près (inévitable).

Un signal utile $S(t)$ traversant un tel filtre adapté donne à la sortie (à un retard T_0 près et à un déphasage près de la porteuse) un signal dont la transformée de Fourier est réelle, constante entre f_0 et $f_0+\Delta f$, et nulle de part et d'autre de f_0 et de $f_0+\Delta f$, c'est-à-dire un signal de fréquence porteuse $f_0+\Delta f/2$ et dont l'enveloppe a la forme indiquée à la figure 5, où l'on a représenté simultanément le signal $S(t)$ et le signal $S_1(t)$ correspondant obtenu à la sortie du filtre adapté. On comprend le nom de récepteur à compression d'impulsion donné à ce genre de filtre adapté : la « largeur » (à 3 dB) du signal comprimé étant égale à $1/\Delta f$, le rapport de compression est de $\dfrac{T}{1/\Delta f} = T\Delta f$

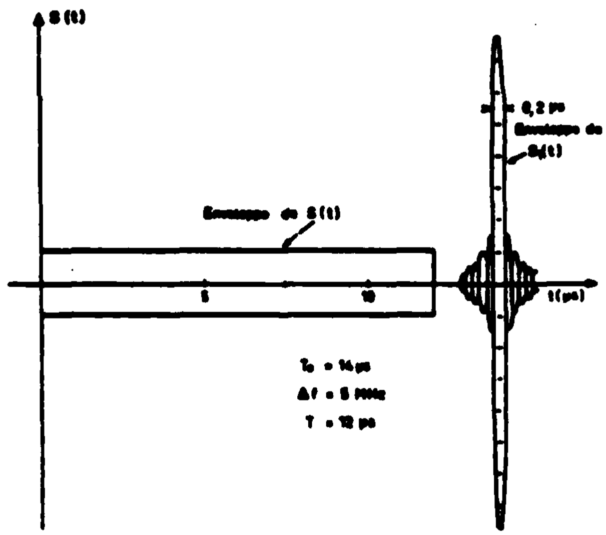


FIG. 5

On saisit physiquement le phénomène de compression en réalisant que lorsque le signal $S(t)$ entre dans la ligne à retard (LAR) la fréquence qui entre la première à l'instant 0 est la fréquence basse f_0, qui met un temps T_0 pour traverser. La fréquence f entre à l'instant $t = (f-f_0)\,\dfrac{T}{\Delta f}$ et elle met un temps $T_0-(f-f_0)\,\dfrac{T}{\Delta f}$ pour traverser, ce qui la fait ressortir à l'instant T_0 également. Ainsi donc, le signal $S(t)$

CCITTの概要

沿革

CCITTは、国際電気通信連合（ITU）の四つの常設機関（事務総局、国際周波数登録委員会、CCIR、CCITT）の一つとして、ITUの中でも、世界の国際通信上の諸問題を真先に取上げ、その解決方法を見出して行く重要な機関である。日本名は、国際電信電話諮問委員会と称する。

CCITTの前身は、CCIF（国際電話諮問委員会）とCCIT（国際電信諮問委員会）である。CCIFは、1924年にヨーロッパに「国際長距離電話通信諮問委員会」が設置され、これが1925年のパリ電信電話会議のとき、正式に、「国際電話諮問委員会」として万国電信連合の公式機関となったものである。CCITは、同じく1925年の会議のとき、CCIFと併立するものとして設置された。

そして、CCIFは、1956年の12月に第18回総会が開催されたのち、CCITは、同年同月に第8回総会が開催されたのち、併合されて現在のCCITTとなった。このCCITTは、CCIFとCCITが解散した直後、第1回総会を開催し、第2回総会は、1960年にニューデリーで、第3回総会は、1964年、ジュネーブで、第4回総会は、1968年、アルゼンチンで開催された。

CCIFとCCITが合併したのは、有線電気通信の分野、とくに伝送路について電信回線と電話回線とを技術的に分ける意味がなくなってきたこと、各国とも大体において、電信部門と電話部門は同一組織内にあること、CCIFの事務局とCCITの事務局の合併による能率増進等がおもな理由であった。

CCITTは、上述のように、ヨーロッパ内の国ぐにによって、ヨーロッパ内の電信・電話の技術・運用・料金の基準を定め、あるいは統一をはかってきたので、現在でも、その影響を受け、会合参加国は、ヨーロッパの国が多く、ヨーロッパで生起する問題の研究が多い。たとえば、1960年のCCITT勧告の中で、技術上記述する頁数は約2,500頁であったが、これはヨーロッパ内領域を想定したものである。

しかしながら、1956年9月に敷設された大西洋横断電話ケーブルは、大陸間電話通信の自動化および半自動化への技術的可能性を与え、CCITTがこの問題を取り上げるに及び、CCITTの性格は漸次、汎世界的色彩を実質的に帯びるに至った。この汎世界的性格は第2次世界大戦後目ざましくなったアジア・アフリカ植民地の独立に伴ってITUの構成員の中にこれらの国が加わり、ITUの中に新しい意見が導入されたことにも起因して、技術面、政治面の双方から導入されてきた。CCITTの汎世界化は、1960年の第2回総会がニューデリーで開催されたことにもあらわれている。この総会までは、CCIT、CCIFのいずれにしろ、アメリカやアジアで総会が開催されたことがなく、CCITT委員長も、ニューデリー総会の準備文書で、この点には注目すべきであるとのべている。

任務

ITUは、全権委員会議、主管庁会議を始めとして、七つの機関をもち、それぞれの機関の権限と任務は国際電気通信条約に明記されている。そこで条約を参照してみるならば、CCITTの任務は、つぎのとおりとなっている。

「国際電信電話諮問委員会(CCITT)は、電信および電話に関する技術、運用および料金の問題について研究し、および意見を表明することを任務とする。」（1965年モントルー条約第187号）

「各国際諮問委員会は、その任務の遂行に当たって、新しい国または発展の途上にある国における地域的および国際的分野にわたる電気通信の創設、発達および改善に直接関連のある問題について研究し、および意見を作成するように妥当な注意を払わなければならない。」（同第188号）

「各国際諮問委員会は、また、関係国の要請に基づき、その国内電気通信の問題について研究し、かつ、勧告を行なうことができる。」（同第189号）

上記第187号と第188号にいわれる「意見」とは、フランス語の Avis から訳したもので、英語では、「勧告(Recommendation)」となっている。CCITTの表明する意見は、国際法的には強制力をもたないものであって、この点が、条約、電信規則、電話規則等各国を拘束する力をもっているものと異なる。もっとも意見とは称しても、技術的分野では、電信規則のごとき、各国政府が承認してその内容を実施する強制規則をもたないので、実際にある機器の仕様を定める場合には、多くの国の意見が統一されたこの「意見」に従わなければ、円滑な国際通信を行なうことができない場合が多い。この意見（または勧告）は、国際通信を行なう場合各国が直面する問題について、具体的意見を表明するもので、たとえば、大陸間ケーブルで大陸間通話を半自動化しようとする場合、その信号方式や取り扱う通話の種類および料金は、どのようにするかを研究して意見を表明する。したがって、CCITTの活動は、つねに時代の最先端を行くもので、CCITTの活動方向は、そのまま世界の国際通信の活動方向であるともいえる。

この意見は、また、電信規則以下のその他の規則のごとく、数年以上の間隔をもって開催される主管庁会議というような大会議の決定をまたなくても表明することができ、また、その改正も容易であるので、現在のように進歩の早い国際通信界では、関係国の意見を統一した国際的見解としては非常に便利である。

Figure 3-7 CCITT Document No. 7

TABLE 3-1
Compressed BITS/PAGE
MODREAD Coding

CCITT DOC. NO		1	5	7	1,5,7
TEST CHART / RESOLUTION lpi	Legibility	English Letter	French Journal	Kanji Text	Avg. CCITT Documents
200lpi	1,136.952	132,034	229,204	531,754	297,664
240	2,170,245	156,880	273,026	628,793	352,899
300	3,148,214	197,476	350,538	798,924	448,979
400	4,476,998	272,312	468,005	1,041,862	594,059
480	5,264,170	326,473	570,302	1,262,734	719,836

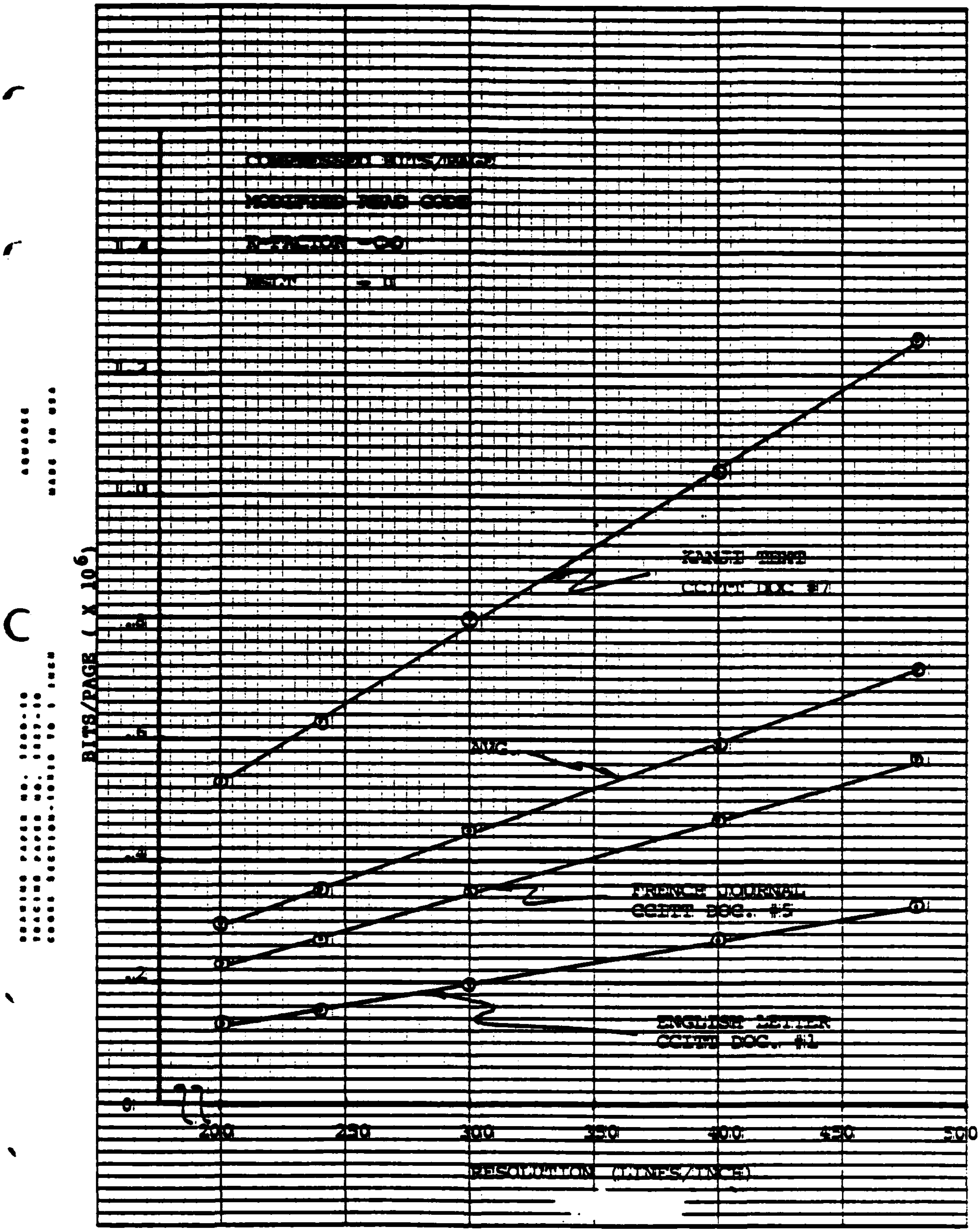

BITS/PAGE (X 10^6)
KANJI TEXT
AVG.
FRENCH JOURNAL
CCITT DOC. #5
ENGLISH LETTER
CCITT DOC. #1
200
250
300
350
400
450
500
RESOLUTION (LINES/INCH)

Figure 3-8

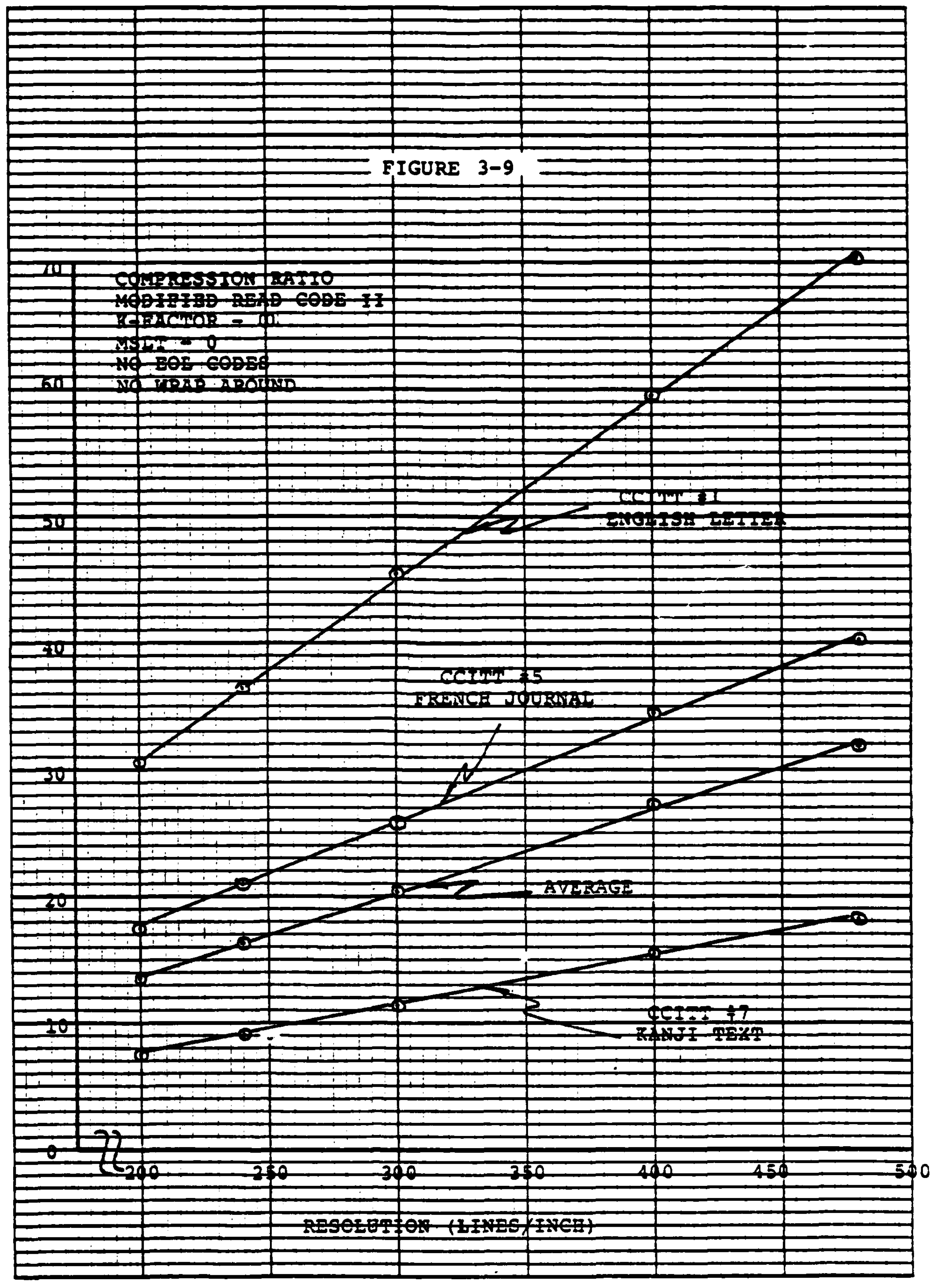
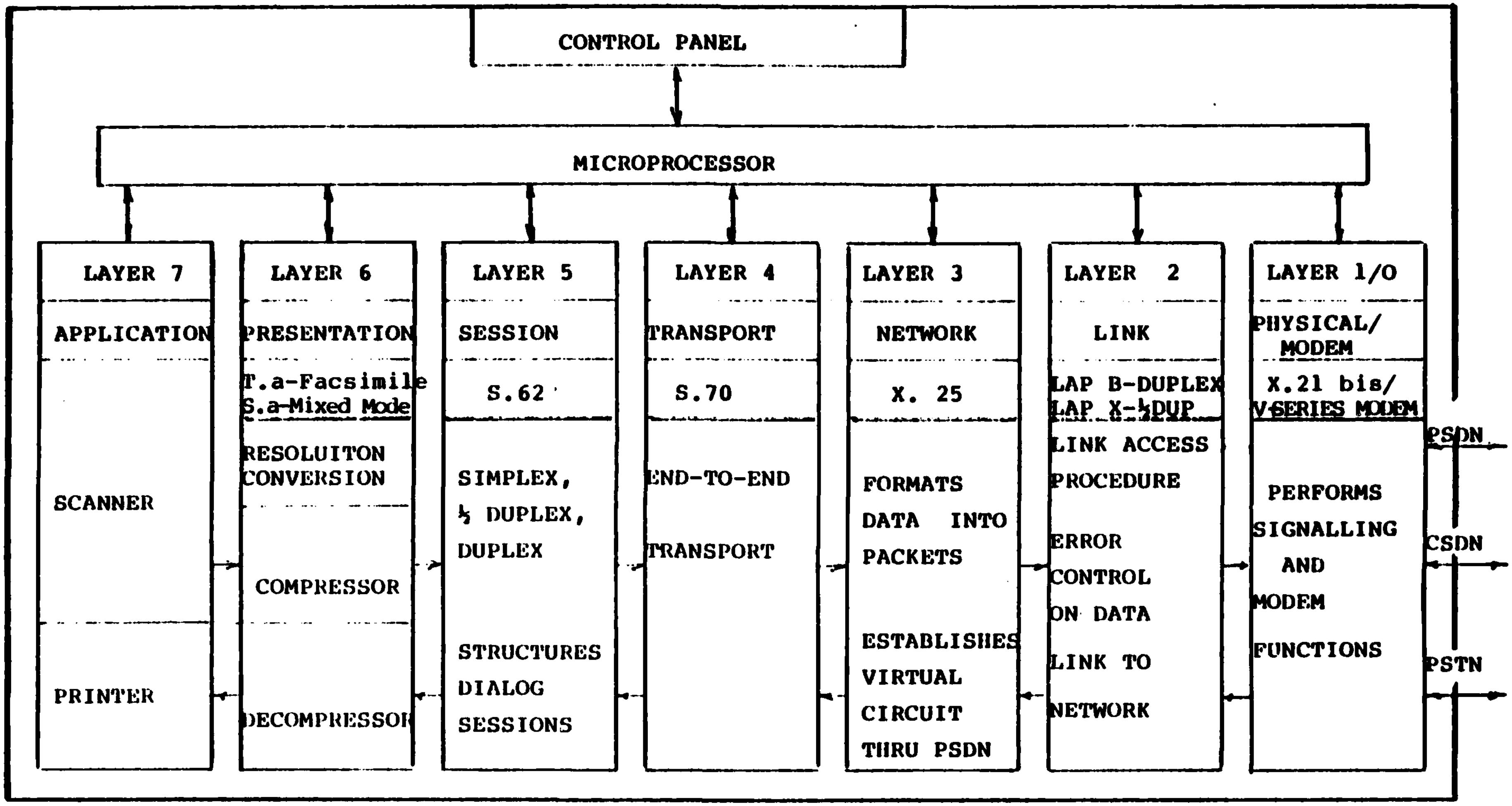


FIGURE 3-9
COMPRESSION RATIO
MODIFIED READ CODE II
K-FACTOR = ∞
MSLT = 0
NO EOL CODES
NO WRAP AROUND
CCITT #1
ENGLISH LETTER
CCITT #5
FRENCH JOURNAL
AVERAGE
CCITT #7
KANJI TEXT
COMPRESSION RATIO
RESOLUTION (LINES/INCH)
0
10
20
30
40
50
60
70
200
250
300
350
400
450
500

3.4 Group 4 Terminal Structure

Figure 3-10 is a functional block diagram of a Group 4 facsimile terminal. It shows how the typical terminal would be microprocessor controlled and how the functions are divided between the seven OSI layers. It is likely that layers 1, 2, and 3 would be implemented largely with LSI hardware. Layers 4 and 5 could be largely software. In high speed systems the compression/decompression in layer 6 could be hardware. Of course the scanner/printer in layer 7 is hardware.

Figure 3-11 is a more detailed functional block diagram of the network-dependent part of the Group 4 facsimile terminal. It shows the details of the implementation for the three types of communication networks.



FUNCTIONAL BLOCK DIAGRAM OF A GROUP 4

FACSIMILE TERMINAL

Figure 3-10

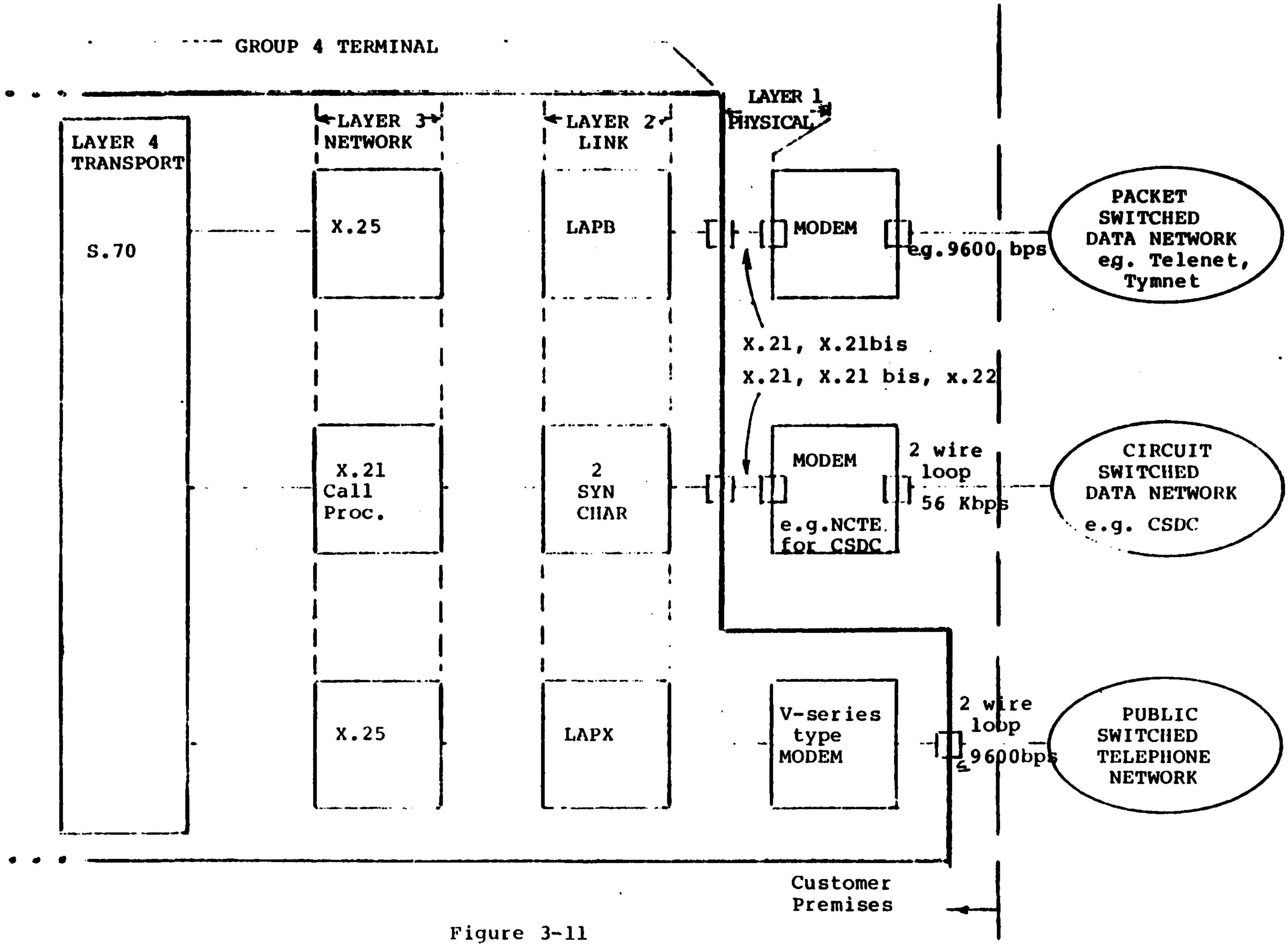


Figure 3-11
FUNCTIONAL BLOCK DIAGRAM OF NETWORK - DEPENDENT PART OF GROUP 4 FACSIMILE TERMINAL

4. Task 3 - Throughput Analysis

4.1 Packet Switched Data Network (PSDN)

4.1.1 Methodology

Throughput for Group 4 Facsimile will be measured as the length of time required to transmit a typical page of facsimile. It includes the time to set up higher protocol levels. In some cases, the higher levels do not have to be set up for each page of a multi-page transmission, so the throughput overstates the time required to transmit multiple pages to a single destination. There are a large number of system parameters that can affect Group 4 Throughput. In order to keep the analysis to manageable proportions, a baseline set of system parameters will be used. All but one of the baseline parameters will be held constant while the one parameter will be varied to demonstrate the sensitivity of the throughput to each parameter value.

4.1.2 Assumptions

The assumed parameters to be used in the analysis are summarized in Table 4-1, and are discussed in the following sections.

Table 4-1

Assumptions for the BASELINE Packet Switched Data Network

Parameter	Baseline Value
Length of facsimile message-bits	500,000
Local signalling rate-bits/sec	9,600
Network signalling rate-bits/sec	56,000
Local error rate	10^{-5}
Network error rate	10^{-6}
Local Propagation Delay-msec	1
Network Propagation Delay-msec	10
Processing Delay-msec	10
Number of Nodes	5
Network Loading	0.8
Packet Size-bytes	128
Transport Block Size-bytes	512
Network Window	6

4.1.2.1 Length of Facsimile Message

The uncompressed image for Class 1 and a North American page format requires 3,740,000 bits. It is assumed that the length of the facsimile message, as encoded by Modified READ II code, is 500,000 bits. This implies a compression of 7.48:1. While 500,000 will be used as an average number of bits per page, for fixed data blocks it will be assumed that an average of an additional one-half data block must always be sent regardless of the exact number of data blocks in 500,000 bits.

Alternate values of 300,000, 400,000, 600,000, and 700,000 bits per page will be used. See Figure 3-8 for the number of bits per page as a function of resolution.

4.1.2.2 Signalling Rates

The Group 4 equipment is connected to the PSDN by means of a relatively slow local circuit, which runs at 9600 bits/sec. Of course this local circuit would apply to both source and sink terminals. Between the nodes of the network, transmission takes place 56,000 bits per second.

4.1.2.3 Raw Error Rates

The errors on all circuits are assumed to be random in nature. The error rate on the local circuits is 10^{-5}, while on the network circuits it is 10^{-6}.

Alternate error rates of 10^{-4} and 10^{-6} will be used for the local links, and 10^{-5} and 10^{-7} for the network links.

4.1.2.4 Propagation Delays

Delays occur because of the finite velocity of propagation. In free space, the delay is about 5 microseconds per mile, while over wires 10 microseconds per mile or more may be more realistic. For each local link, which will be relatively short, a one-way delay of 1 millisecond can be assumed. For node-to-node links where the distances could be much longer, a delay of 10 milliseconds will be used. Of course, if satellites are used for node-to-node transmission, a delay of 250 milliseconds or more would be experienced. This will not be used for

the baseline system but will be used as an alternative.

4.1.2.5 Processing Delays

At each node, after the entire packet has been received, a certain amount of computer processing must take place before the packet is ready to be placed in a transmission queue. The processing that must take place includes looking up the proper routing and changing the Logical Channel Number, and producing an appropriate ACK to be sent to the sender. It is assumed that a processing delay of 10 milliseconds will be experienced at each node, and at the sink Group 4 equipment.

4.1.2.6 Number of Nodes

It is assumed that the average message passes through 5 nodes, which seems to be typical for TELENET. Therefore the baseline transmission will take place over the network shown in Figure 4-1.

Alternate numbers of nodes of 1, 2, 3, 8, and 10 will be considered.

4.1.2.7 Network Loading

Because of other users of the network, packets will form into queues at the nodes, awaiting transmission to another node. The loading of the circuit is assumed to be 0.8, with all other packets of the same length and priority as the facsimile data packet. It is assumed that each Group 4 equipment is the only one on its circuit, and that it is dedicated to transmission or reception, so that no queues will form for transmission to or from a Group 4 equipment.

Alternate loadings of 0, 0.5, 0.9, and 0.95 will be used.

PSDN

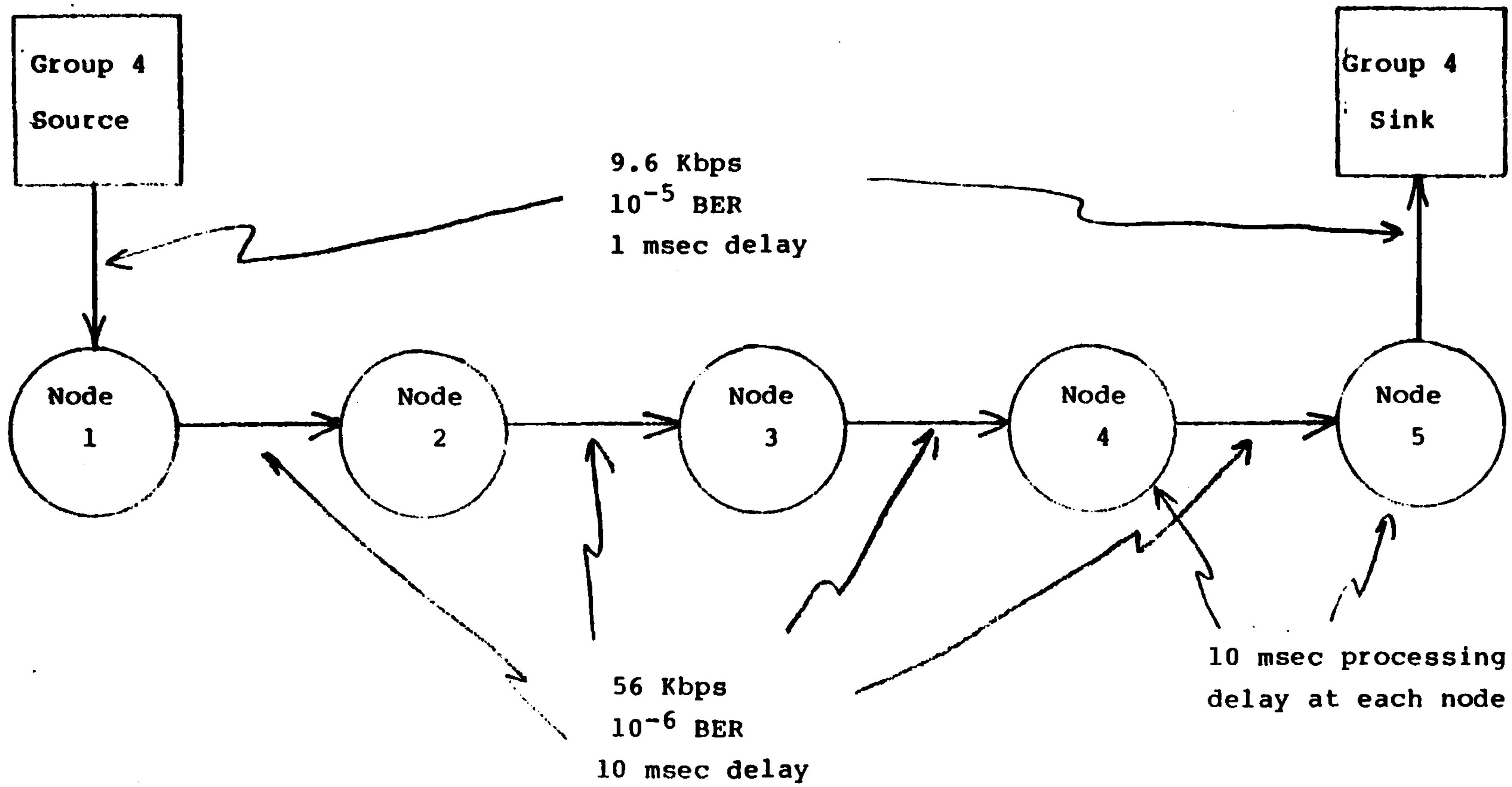


Figure 4-1

PSDN BASELINE NETWORK

4.1.2.8 Windows

The window is the number of data packets that may be outstanding from a source, without an acknowledgement being received. Windows are used to control the rate of flow of data into the network. Flow control can exist at the link and network levels. At the link level, it is assumed that the window is large enough not to slow the flow of data at all. At the network level, it is assumed that the window is large enough not to slow the data flow significantly when the network loading is light.

Note that the window is something that is arrived at by negotiation of the user and the network operator. A large window can yield a high throughput for the user. To the network operator, however, this means that the user has the capability to cause network congestion, and therefore the user must pay more for the capability. Unless restricted by the window, a single user in the baseline system will have the capability to use 17 percent of the network link capacity.

4.1.2.9 Packet Size

The current TELENET system uses a packet size of 128 bytes of user data. While larger sizes may be permitted in the future, the baseline assumption will be 128 bytes per packet.

Alternate packet sizes of 256 and 512 bytes will be considered.

4.1.3 Baseline Throughput Calculations

The average time required to transmit an entire facsimile page, from the initiation of transmission until the final acknowledgement and tear-down of the virtual circuit, will be calculated using the baseline parameters from Table 4-1. The calculation of the overhead, and the time required for it, will progress from the lowest protocol levels to the highest. The various protocol levels are displayed in Figure 3-3.

A given protocol may add overhead to the basic FAX signal in many ways. The addition of sync codes or other header information is an obvious example. In addition, there may be bits used for error control, and the retransmissions required when errors are detected but not corrected. When a unique sync pattern is used to indicate the end of a data block, bits may have to be stuffed into the data stream to prevent the inadvertant occurrance of the sync pattern. Where data blocks have a fixed length, the actual length of the data stream may not require an exact number of blocks. The unused portion of the last data block is a form of overhead.

If two Group 4 machines were connected back-to-back, and the transmission rate was 9600 bits/sec, then the total transmision time would be 500,000/9600 = 52.08 seconds. This is the basic time required for transmission, without any overhead from the various protocols involved in transmission. To this time must be added the overhead from each of the protocol levels.

4.1.3.1 Physical/Modem Overhead

There is no overhead at this level that contributes to message throughput.

4.1.3.2 Link Overhead

The Link Level is defined in X.25 and X.75. The format of the link message is shown in Table 4-2.

Table 4-2

LINK OVERHEAD

	8	7	6	5	4	3	2	1	Order of Transmission
1	0	1	1	1	1	1	1	0	FLAG
2	0	0	0	0	0	0	0	1	ADDRESS
3	N(R)			P/F	N(S)			0	CONTROL
4									
5	NETWORK								
6	HEADER								
7									
8									
	USER DATA								BIT
	128 bytes max								STUFFING
135									
136	FRAME CHECK								
137	SEQUENCE								
138	0	1	1	1	1	1	1	0	FLAG

The first byte is a flag containing a unique sequence of six one's, which syncronizes the receiver. The second byte is an address on the local circuit. Although it uses an entire byte, it can have only two values 00000001 or 00000011, depending on whether it is a command or response, and which of the two units originated it. The third byte is a control field. The 3-bit N(S) value is a serial number for the transmitted packet that is expressed module 8. The 3-bit N(R) is the

last serial number received in the other direction. The P/F bit (Poll/Final) is normally Ø, unless the packet in question is being retransmitted because of an error. The first bit of the byte is Ø for a data packet, but is 1 for supervisory frames, such as a pure acknowledgement.

The link level header is followed by the network level header, which is described in Section 4.1.3.3.1, and which uses 4 bytes. This is followed by up to 128 bytes of user data, which includes higher level overhead. After the user data is the Frame Check Sequence (FCS), which is used to detect, but not correct, transmission errors. This uses 2 bytes. Finally, the packet is ended by another flag, which locates the FCS for the receiver. If the data is continuous, the last flag is not needed, since it is replaced by the first flag of the next packet.

4.1.3.2.1 Stuffing Bits

In order to preserve the uniqueness of the flag, the transmitter must monitor all the bits sent between the flags. If it detects 5 consecutive ones it automatically stuffs a zero in order to avoid 6 consecutive ones. The receiver deletes a zero following 5 consecutive ones to recover the original data. For random data, the average number of stuffing bits is given by:

$$\frac{L}{2^N-2}$$

where L is the number of bits between flags (L>>N), and N is the number of successive ones in the flag. This is derived in Appendix C. Here N=6, so the average number of stuffing bits is $\frac{L}{62}$. For the full 128-byte data packet L=8(128+8)=1Ø88, so 1Ø88/62=18 stuffing bits will be used for each data packet. Since there are $\frac{500,000}{128\text{x}8}$=489 packets in

the transmission, the stuffing bits add $\frac{18x489}{9600}$=.92 seconds to the transmission time.

4.1.3.2.2 Source Error Retransmission

Packets for which the FCS is in error are discarded by the receiver, without notifying the transmitter. However, when the next packet is received, it will not have the correct serial number, N(S). This will cause the receiver to issue a REJ command to the sender, indicating the serial number of the last packet received correctly. The transmitter must go back and retransmit all packets after the last one acknowledged, in their correct order.

A data packet contains 138 bytes, or 8 x 138 = 1,104 bits, plus 18 stuffing bits, for a total of 1,122 bits. With the assumed bit error rate of 10^{-5}, the probability of at least one error in a packet is approximately:

$$1,122 \times 10^{-5} = 0.01122$$

Neglecting higher levels of protocol, the total number of data packets in a transmission is 489. Therefore the expected number of data packets received in error is: .01122 x 489 = 5.49. The total time required to transmit a data packet is

$$\frac{1122}{9600} = 0.117 \text{ sec.} = 117 \text{ msec.}$$

Now assume that packet 1 is transmitted correctly, and that packet 2 is received in error and discarded. Then packet 3 is transmitted correctly, and following 10 msecs processing delay a REJ command is issued to the transmitter. The REJ command is much shorter than a data packet. However, by this time packet 4 is already being transmitted.

After packet 3 has been transmitted, the delay before the REJ is

received can be calculated as:

	msec
Propagation delay, 2-way 2x1	2
Processing at node	10
Transmission of ACK - 6 bytes	5
	--
	17 msec

This represents 17/117=0.145 of a data packet. When REJ is received, packets 2, 3, and 4 are retransmitted. Assuming that the transmission of packet 4 can be interrupted, 2.145 data packets were transmitted that will be retransmitted. Therefore a total of 5.49 x 2.145 = 12 additional packets must be transmitted because of local link errors, or a total of 489+12=501 packets. The 12 additional packets add 12 x 0.117 = 1.40 seconds to the total transmission time.

The effect of errors on the ACK's is somewhat different. First, the ACK packets are considerably shorter, and therefore have a smaller chance of being in error, assuming that there is no flow of data to the sending Group 4 equipment. Second, if an ACK is discarded because of a transmission error, the only effect is to increase the number of packets outstanding. If the link window does not stop transmission, the next ACK will acknowledge two packets and no retransmission is required. Only if a number of ACK's in a row are lost will there be any impact on throughput, providing the link window is large enough (say 3 or more).

4.1.3.2.3 <u>Sink Error Retransmission</u>

Errors will also be made on the local link to the sink Group 4 equipment. These will cause a queue to form at the last node, and may

cause a delay in delivering the last packet. However, delays on this circuit may be offset by delays on the source local circuit, caused by transmission errors or window requirements. For example, a net delay is improbable if the last error on the sink local link occurs before errors on the source local link. The delay incurred for each error is 2.145 x 117 = 251 msec. This delay will occur if one sink error occurs after the last source error. This will happen with probability 1/2, for an average delay of one msec. A larger sequence of sink delays will occur with lower probabilities, as shown in Table 4-3.

Table 4-3

Calculation of Sink Error Retransmission Delay

last N	Delay	Prob.	msec
1	251	1/2	125
2	502	1/4	125
3	753	1/8	94
4	1004	1/16	63
5	1255	1/32	39
6	1506	1/64	24
7	1757	1/128	14
8	2008	1/256	8
9	2259	1/512	4
10	2510	1/1024	2
			498 = 0.50 sec.

The summed average delay amounts to 0.50 seconds.

There is an interaction between the sink errors and the window delays. A stoppage of transmission due to window limits after the last sink error will reduce the effect of the error. On the other hand, a

packet that had to be retransmitted due to a sink error has a much higher probability of exceeding the window, due to the increased delay. Therefore the 0.5 second time is only a rough estimate of the additional transmission time required due to errors on the sink local circuit.

4.1.3.2.4 Set-up Link

This link is set up by the transmission of a supervisory message, and the receipt of its acknowledgement. Each message requires only 6 bytes, so it takes only

$$\frac{6 \times 8}{9600} = 5 \text{ msec}$$

to transmit each message, or a total of 10 msec. To this must be added the two-way propagation delay, 2 msec, and the processing time, 10 msec. This gives a total of 22 msec to set up the link, so 0.02 sec must be added to the total transmission time.

4.1.3.3 Network (Packet) Overhead

The Network header format, which requires 4 bytes, is shown in Table 4-4.

Table 4-4

NETWORK HEADER

	8	7	6	5	4	3	2	1
4	Ø	Ø	1	Ø	Logical			
5	Channel Number							
6	P(S)							Ø
7	P(R)							M

In byte 4, bit 8 indicates that the packet contains data, bit 7 indicates that end-to-end ACK is required, and bits 5 and 6 shows that an extended numbering scheme is in use. The extended numbering requires an extra byte per packet, but increases the numbering from modulo 8 to modulo 128, thereby allowing a larger network window. The Logical Channel Number (LCN) is used for each link to identify the virtual circuit that has been set up for this transmission. P(S) and P(R) are packet serial numbers that are used in a similar way to the link serial numbers. However, here their main function is flow control, not error control. The M bit is normally zero. The last packet has M=1, which indicates that the virtual circuit is to be torn down.

4.1.3.3.1 Network Header

There are 4 network header bytes in each packet. Since there are 489 packets in a message, the additional transmission time is given by

$$\frac{4 \times 8 \times 489}{9600} = 1.63 \text{ seconds}$$

4.1.3.3.1 Halts Due to Window

The time required to transmit a data packet from one node to another at 56Kbps is

$$\frac{1,122}{56,000}=20 \text{ msec.}$$

The time for an ACK (RR) packet (80 bits) is 1 msec. The total time required to transmit a data packet and receive an ACK, neglecting queues, can be calculated as follows:

		msec
Local Transmission of data packet	2x117 msec	234
Network Transmission of data packet	4x20 msec	80
Local Transmission of RR	2x8 msec	16
Network Transmission of RR	4x1 msec	4
Local propagation delay	4x1 msec	4
Network propagation delay	8x10 msec	80
Processing delay (5 nodes twice plus Group 4)	11x10 msec	110
		528 msec

During this time about 4.5 packets will have been transmitted. Therefore a window of at least 5 is required if the data flow is not to be restricted in an idle network.

At each node the packet experiences an average delay due to the transmission queue. For a fixed packet transmission time, this average delay is:

$$\frac{\rho t_s}{2(1-\rho)}$$

where ρ is the network loading, and t_s is the time required to transmit a packet. For $\rho=0.8$ and $t_s=20$ msec, the mean queue delay at each node is 40 msec. This delay is in addition to the time required to actually transmit the packet.

Since the data packet experiences a queue at 4 nodes, and the ACK

also experiences delays at 4 nodes, the total average delay due to congestion is m=8x40=320 msec.

However, in addition to experiencing an average delay at each node, there is a variation of this delay owing to the random nature of the queue, even with fixed service times. The variance of the time spent waiting in a transmission queue is given by1/:

$$\sigma_{TW}^2 = \frac{t_s^2}{(1-\rho)^2}\left(\frac{\rho}{3} - \frac{\rho^2}{12}\right)$$

For t_s=20 msec and ρ=0.8, the variance is 2133.33 $(\text{msec})^2$

Because the nodes are assumed to be identical, but statistically independent, the variance also adds, and even for a relatively small number of nodes the delay distribution will be approximately normal, because of the Central Limit Theorem. Since the normal distribution is completely defined by its mean and variance, higher order moments are not required. The total variance is therefore 8x2133.3317067 $(\text{msec})^2$ which gives a standard deviation of $\sigma=(17067)^{1/2}$ = 131 msec.

The source must halt transmission if the window is exceeded. The effect of queue delays that are longer or shorter than the average delay on halt times will be considered. A delay longer than average could cause the window to halt transmission. This stoppage of transmission is not compensated for by a shorter than average delay since there is a

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1/ Martin, James, Systems Analysis for Data Transmission, Prentice-Hall, Englewood Cliffs NJ, 1972, p. 472.

limit on the transmission rate. Let us first assume that there is no halt time due to the window for all packets but the one under consideration. Then the expected halt time of that packet is given by $H=\sigma F(w)$ where $F(w)=\int_{w}^{\infty}(t-w)p(t)dt$ and $p(t)$ is the normal density function,

$$p(t) = (2\pi)^{-1/2} \exp(-t^2/2)$$

Now w is the difference between the time required to transmit W packets and the average delay in receiving the ACK, expressed in units of σ. Therefore

$$w=\frac{WL-m}{\sigma}$$

where L is the packet transmission time. As shown in Appendix D

$$F(w)=p(w)-wQ(w) \qquad \text{(a)}$$

where $Q(w)=1-P(w)=\int_{w}^{\infty}p(t)dt$ is a tabulated function[2/]. F(w) has been calculated, and is plotted in Figure 4-2.

Since F(Ø)=Ø.4, even if the average packet ACK makes it back to the source before the expiration of the window, an average halt time of Ø.4x13Ø.64=52.26 msec will occur for each packet. Since there are 489 packets in the transmission, the total delay due to the window would be 489x52.26 msec=25.55 sec. Because of this large delay, it is important to have a window that is substantially longer than the average round-trip delay.

However, because the packets immediately prior to the one under consideration may have been halted, a longer time is available between the time the original packet was transmitted and the (W+1)st packet can

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2/ National Bureau of Standards, Handbook of Mathematical Functons, AMS 55, p931.

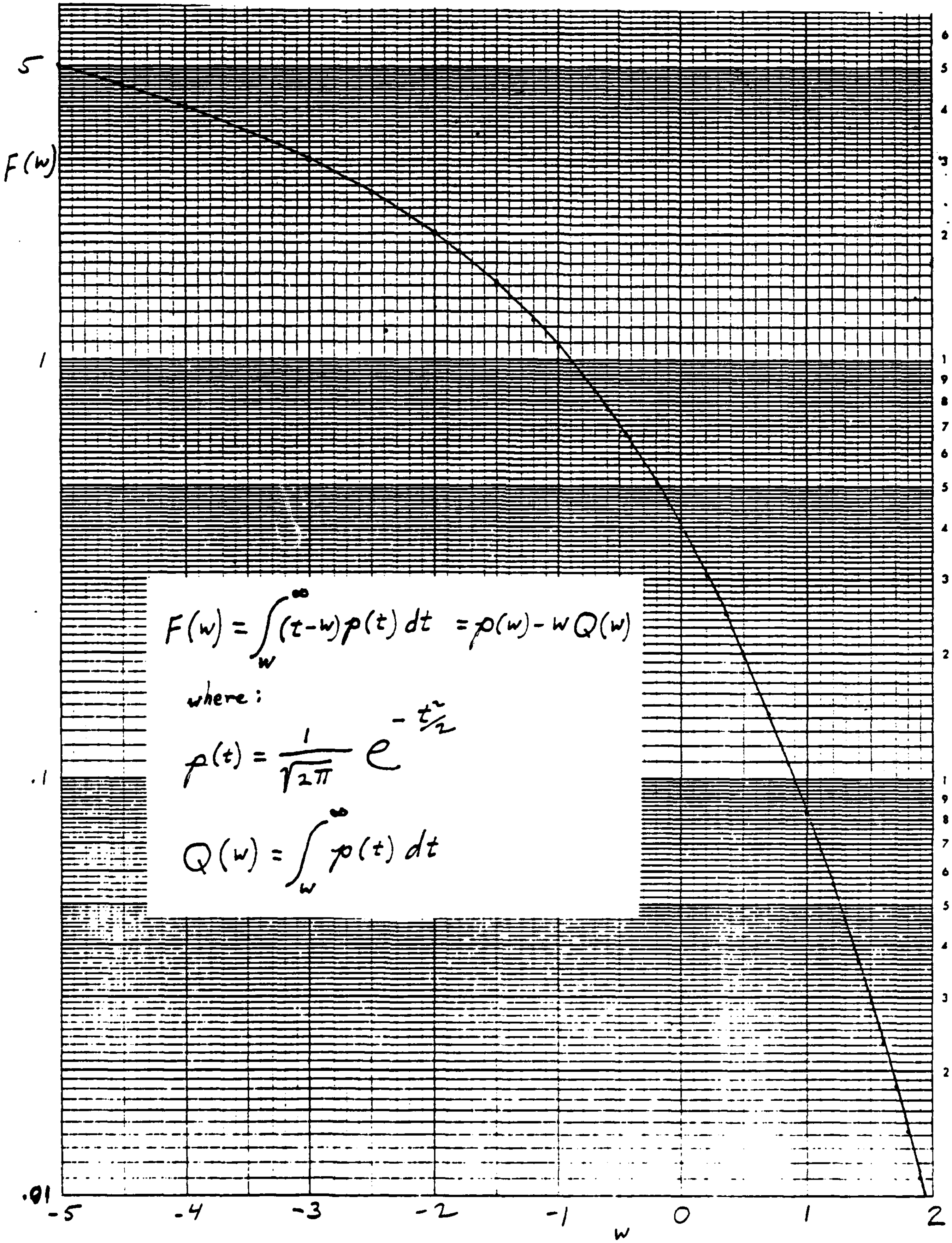


Figure 4-2
Plot of F(w)

be transmitted. In between, W-1 packets could have been halted, so the time is increased by an average of (W-1)H. Therefore w is given by:

$$w = \frac{WL+(W-1)H-m}{\sigma} \qquad \text{(b)}$$

Since w is required in Equation (a) to calculate F(w), which then gives the average halt time H, an assumption must be made for the value of H which is then used in Equation (b) to calculate a trial w. The trial w is then used in Equation (a) to calculate H. The value of H from Equation (a) is compared with the assumed H, and the assumed value of H is adjusted until it agrees with the result from Equation (a). This iterative process has been performed and the results expressed in Table 4-5 and plotted in Figure 4-3. These calculations have been checked by means of a simulation run on a digital computer, and the results compared in Figure 4-4. Note that the simulation gives slightly larger values for H than the calculations. One reason for this is that the variance of the halt time was neglected. This will add to the total variance and slightly increase the average halt time.

4.1.3.3.3 Link Errors

Errors on the network links should not have much influence on throughput. First, the raw error rate is an order of magnitude lower than the local link error rate, so proportionately fewer packets will have errors. Less than one data packet in the entire message is expected to be in error over a given network link. Even when a packet is in error, the time required to detect the error and retransmit the packet (60 msec) is shorter than the time it takes to generate a packet at the source (117 msec), so packets will not get out of order because of errors. This is especially true if retransmitted packets are given priority in the transmission queue. Only if an error packet coincides

Table 4-5

Average Packet Halt Time (msec)

	Network Loading			
Window	.5	.8	.9	.95
2	187	307	508	913
3	86	168	306	582
4	37	101	207	419
5	10.0	61	148	322
6	.20	36	109	256
7		20	82	209
8		8.5	61	173
9		2.4	45	146
10		.28	33	124
11		.014	23	106
12			15.5	90
13			9.6	77
14			5.3	66
15			2.4	56
16			.9	48
17				41
18				34
19				29
20				24
25				6.7
30				.6

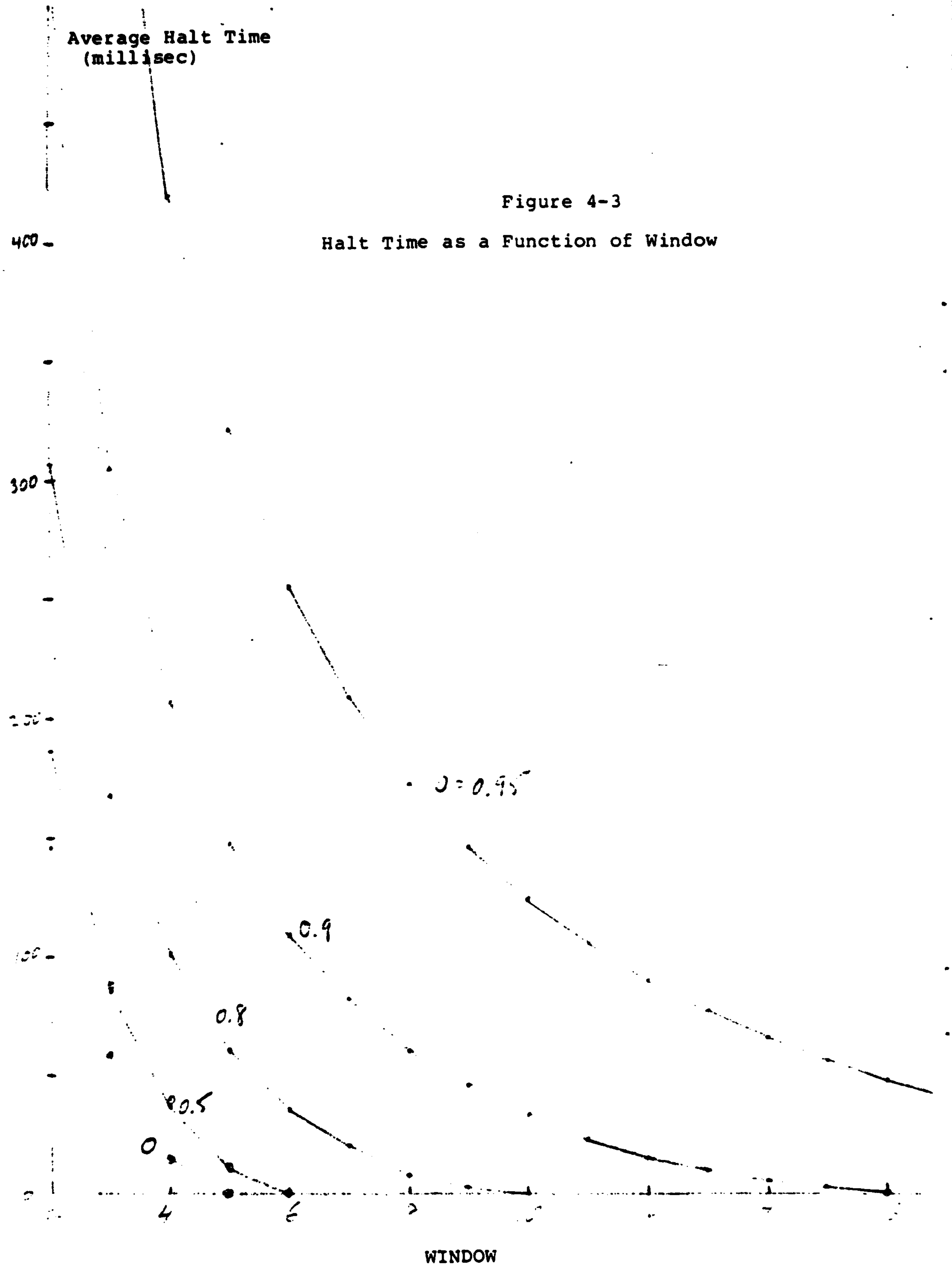


Figure 4-3

Halt Time as a Function of Window

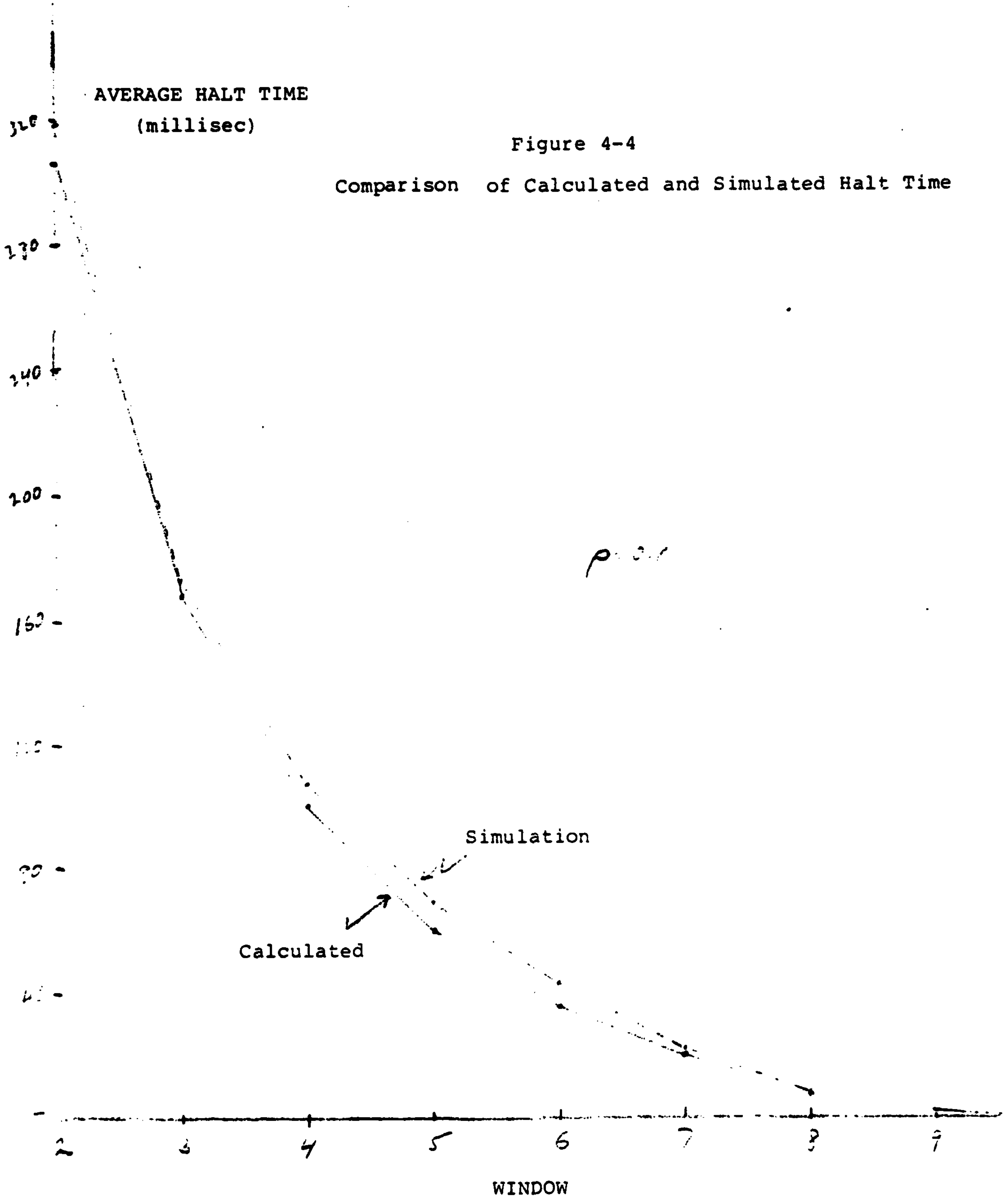


Figure 4-4

Comparison of Calculated and Simulated Halt Time

with long queue delays that exceed the window would network errors affect throughput.

4.1.3.3.4 Set-up Network

Before data packets can be transmitted, a virtual circuit must be set up between source and sink Group 4 equipments. This is done by the source sending a Call Request packet to the sink, and the sink responding with a Call Connected packet. Each of the packets contains, in addition to the usual overhead, the called and calling addresses, the Network Utilities, and the User Facilities. These packets will be shorter than the data packets, perhaps 25 bytes, or 200 bits. This will take 21 msec to transmit locally and 4 msec in the network. The time delay calculation is similar to before, except for the transmission time.

		msec.
Local Transmission of packets	4x21 msec	84
Network Transmission of packets	8x4 msec	32
Local propagation delay	4x1 msec	4
Network propagation delay	8x10 msec	80
Processing Delay	11x10 msec	110
Queues	8x40 msec	320
		630 msec

Therefore setting up the virtual circuit requires 0.63 sec, which must be added to the total transmission time.

4.1.3.3.5 Final ACK

After the last packet has been transmitted by the source Group 4 equipment, it must wait for the ACK from the sink Group 4 equipment

before it can tear down the virtual circuit and start the next transmission. The ACK consists of 10 bytes, and requires 8 msec for local transmission, and 1 msec for network transmission. The delay can be calculated as follows:

		msec
Local Transmission of packet (at sink)	1x117 msec	117
Local Transmission of ACK	2x8 msec	16
Network transmission of packet	4x20 msec	80
Network transmission of ACK	4x1 msec	4
Processing delay	11x10 msec	110
Local propagation delay	4x1 msec	4
Network propagation delay	8x10 msec	80
Queues	8x40 msec	320
		731 msec

Therefore 0.73 sec must be added to the total transmission time.

4.1.3.4 Transport Overhead

The Transport Level is defined by S.70. There are three factors to consider in determining Transport Level overhead. They are: 1) The time required to set up (or tear down) a transport level connection before data is transmitted. 2) The length of the header that must be transmitted with each Transport Level block. 3) The extra bits that must be transmitted at the end of the message because the Transport blocks have a fixed length.

4.1.3.4.1 Transport Set-up

The Transport Connection Request (TCR) is sent from the source Group 4 equipment to establish the Transport connection. The sink

replies with a Transport Connection Accepted (TCA) message. The format of the TCR message is shown in Table 4-6.

Table 4-6

TRANSPORT CONNECTION REQUEST (TCR)

	8	7	6	5	4	3	2	1	Order of Transmission
1	0	0	0	0	1	0	0	1	LENGTH INDICATOR -9
2	1	1	1	0	0	0	0	0	BLOCK TYPE-TCR
3	DESTINATION REFERENCE								
4	(blank in TCR)								
5	SOURCE REFERENCE								
6									
7	0	0	0	0	0	0	0	0	BLANK
8	1	1	0	0	0	0	0	0	PARAMETER TYPE CODE
9	0	0	0	0	0	0	0	1	PARAMETER LI-1
10	0	0	0	0	1	0	0	1	TDT SIZE - 512 bytes

It requires 10 bytes. The TCA is similar, except that the block type is coded 11010000. The TCR and TCA establish the fixed block size for subsequent transmission of data. Adding the 10 bytes for the Transport message to the 10 bytes required in each packet, gives a total of 20 bytes. The transmission time will be 17 msec over local links, and 3 msec over network links. Therefore, the total time to establish the transport connection can be calculated as:

			msec
Local Transmission of packets	4x17 msec		68
Network Transmission of packets	8x3 msec		24
Local propagation delay	4x1 msec		4
Network propagation delay	8x10 msec		80
Processing delay	11x10 msec		110
Queues	8x40 msec		320
			606 msec

Therefore 0.61 sec must be added to the total transmission time.

The transport level is torn down by simply setting the Transport Service Data Unit (TSDU) bit in the header of the last block (see Table 4-7), so no additional overhead is required.

Table 4-7

TRANSPORT DATA BLOCK (TDT)

	8	7	6	5	4	3	2	1	Order of Transmission
1	0	0	0	0	0	0	1	0	LENGTH INDICATOR -2
2	1	1	1	1	0	0	0	0	BLOCK TYPE -TDT
3		0	0	0	0	0	0	0	
4									
	SESSION DATA								
512									

TSDU end

4.1.3.4.2 Transport Header

The data itself is sent in Transport Data (TDT) blocks, which have a 3-byte header as shown in Table 4-7. Block sizes up to 2048 bytes can be used, and it might appear that the largest possible block size would minimize the overhead. However, it should be remembered that on the average an additional one-half block must be transmitted at the end of the message because of the fixed block size. Hence there is an optimum block size of 512 bytes which can be seen in Table 4-8.

Table 4-8

Minimization of Transport Level Overhead

Transport Block Size (bytes)	256	512	1024	2048
Header bytes in 500,000 bits	741	368	184	92
One-half block (bytes)	128	256	512	1024
Total overhead (bytes)	869	624	696	1116

This block size will be used for subsequent calculations. On the average, therefore, 368 additional header bytes will have to be transmitted for transport level protocol, which will take 3 extra packets at 128 bytes per packet. This will require an extra 351 msec of transmission time over the local circuit, so an additional 0.35 sec must be added to transmission time.

4.1.3.4.3 Final Block

As shown in Table 4-8, for a 512-byte transport block, an average of 256 extra bytes will have to be transmitted at the end of the message. This will take an extra two packets, which requires 234 msec. Therefore 0.23 sec must be added to the total transmission time.

4.1.3.5 Session Overhead

The Session Level is defined by S.62. The only overhead involved at the Session Level is the requirement to set up the session. To do this, the source sends a Command Session Start (CSS) which is acknowledged by a Respond Session Start Positive (RSSP). The format of a typical CSS is shown in Table 4-9. The data follows the sequence Parameter Indicator (PI), Length Indicator (LI), and Parameter Value (PV). Multiple parameters can be grouped under Parameter Group Indicator (PGI), followed by the LI for the data in the group. The

Octet	8	7	6	5	4	3	2	1	Order of Transmission	
1	0	0	0	0	1	1	0	1	PI	CSS
2	0	1	0	1	0	1	1	0	LI	86
3	0	0	0	0	0	0	0	1	PGI	Session Reference
4	0	1	0	0	1	0	0	0	LI	68
5	0	0	0	0	1	0	0	1	PI	Called Terminal Identifier
6	0	0	0	1	1	0	0	0	LI	24
7-30	Called Terminal No.								PV	
31	0	0	0	0	1	0	1	0	PI	Calling Terminal Identifier
32	0	0	0	1	1	0	0	0	LI	24
33-56	Calling Terminal No.								PV	
58	0	0	0	0	1	1	1	0	LI	14
59-72	Date & Time								PV	
73	0	0	0	0	1	0	0	0	PI	Service Identifier
74	0	0	0	0	0	0	0	1	LI	1
75	0	0	0	0	0	0	1	0	PV	Group 4 Facsimile
76	0	1	1	0	0	0	0	1	PGI	Fax Capabilities
77	0	0	0	0	1	0	0	1	LI	9
78	0	0	0	1	1	1	0	1	PI	Page Format
79	0	0	0	0	0	0	0	1	LI	1
80	1	0	0	0	0	1	0	0	PV	A4 Extended, Vert.
81	0	0	0	1	1	1	1	0	PI	Image Coding
82	0	0	0	0	0	0	0	1	LI	1
83	0	0	0	0	0	0	0	1	PV	Wrap-Around
84	0	0	0	1	0	0	0	1	PI	Resolution
85	0	0	0	0	0	0	0	1	LI	1
86	0	0	0	0	0	0	0	1	PV	240 Pels/inch

Table 4-9

COMMAND SESSION START (CSS) FORMAT

format for the RSSP is similar. Each requires about 86 bytes, depending on the amount of non-standard parameters to be established, which added to the 10 bytes for packet overhead requires a total of 96 bytes. This requires 80 msec to transmit over a local link, and 14 msec over the network links. Therefore, the time required to initiate the session may be calculated as:

		msec
Local Transmission of packets	4x80 msec	320
Network Transmission of packets	8x14 msec	112
Local propagation delay	4x1 msec	4
Network propagation delay	8x10 msec	80
Processing delay	11x10 msec	110
Queues	8x40 msec	320
		946 msec.

Thus, 0.95 seconds must be added for Session overhead.

At the Session Level, there is also a Document protocol. The transmission of a document is preceded by a Command Document Start (CDS). This format is shown in Table 4-10. Since it does not require an acknowledgement, the time required to propagate to the sink and back is of no consequence. In fact, CDS may be followed in the same packet by the facsimile data itself. Therefore the only delay is the time required to transmit 5 bytes over the local link, which is only 4 msec, which can be neglected.

4.1.3.6 Presentation and Application Overhead

The exact nature of the overhead at these levels has not yet been defined. It appears that it will add very little to the overall

Table 4-1Ø

COMMAND DOCUMENT START (CDS) FORMAT

	8	7	6	5	4	3	2	1	Order of Transmission	
1	Ø	Ø	1	Ø	1	1	Ø	1	PI	CDS
2	Ø	Ø	Ø	Ø	Ø	Ø	1	1	LI	3
3	Ø	Ø	Ø	Ø	Ø	Ø	Ø	1	PI	Document Reference No.
4	Ø	Ø	Ø	Ø	Ø	Ø	Ø	1	LI	1
5	Ø	Ø	Ø	Ø	Ø	Ø	Ø	1	PV	Document Reference No.
6	Facsimile Data									

transmission time, and will therefore be neglected.

4.1.3.7 Summary of Baseline Throughput

Table 4-11 summarizes the calculations made for the PSDN throughput. The total transmission time, 80.10 sec, is 54% more than the minimum transmission time of 52.08 sec. The dominant factor in the overhead is the halt time required because of the control of the window over transmission rate, thereby avoiding network congestion.

Table 4-11

Baseline Throughput Calculation Summary

Packet Switching Data Network

	Seconds
Basic FAX Transmission	52.08
Link Overhead	
Header	2.45
Stuffing Bits	.92
Source Error Retrans.	1.40
Sink Error Retrans.	.50
Set-up	.02
Network Overhead	
Header	1.63
Window	17.60
Link Error Retrans.	
Set-up	.63
Final ACK	.73
Transport Overhead	
Set-up	.61
Header	.35
Final Block	.23
Session Overhead	
Set-up	.95
Total Transmission Time	80.10

4.1.4 Sensitivity of Throughput to Baseline Assumptions

In order to determine the sensitivity of the results presented in Section 4.1.3 to the assumptions used in the baseline system, a selected set of baseline parameters were varied one at a time and the throughput calculated. The following sections discuss the variations used and the results obtained.

4.1.4.1 Network Loading

In addition to the baseline loading of 0.8, network loadings of 0, 0.5, 0.9, and 0.95 were used. The network loading, ρ, affects the length of the transmission queues that form at each node. These queues delay the delivery of packets and acknowledgements. The primary effect is that the window halts transmissions from the source at high loadings. This is expected, since the window is the network's method of fairly allocating resources during congested periods by reducing the degree to which any user can load the network. In addition, procedures that require round-trip propagation, such as the set-up of Network, Transport, and Session protocols, also require a longer time when traffic is heavy.

Table 4-12 summarizes the throughput calculations for various network loadings. It can be seen that network loading has very little effect up through ρ = 0.5, and that throughput becomes prohibitively poor at ρ = .95. Therefore the network accepts FAX messages as fast as the Group 4 equipment can generate them during light loading, but severely restricts throughput during very heavy loading, which is as it should be. From this point of view the choice of a window of 6 appears to be appropriate.

Table 4-12

Throughput Calculation Summary

Packet Switching Data Network

Network Loading ρ	Ø	.5	.8	.9	.95
Basic FAX Transmission	52.Ø8	52.Ø8	52.Ø8	52.Ø8	52.Ø8
Link Overhead					
Header	2.45	2.45	2.45	2.45	2.45
Stuffing Bits	.92	.92	.92	.92	.92
Source Error Retrans.	1.4Ø	1.4Ø	1.4Ø	1.4Ø	1.4Ø
Sink Error Retrans.	.5Ø	.5Ø	.5Ø	.5Ø	.5Ø
Set-up	.Ø2	.Ø2	.Ø2	.Ø2	.Ø2
Network Overhead					
Header	1.63	1.63	1.63	1.63	1.63
Window Halts	Ø	.1Ø	17.6Ø	53.3Ø	125.18
Link Error Retrans.	-	-	-	-	-
Set-up	.31	.39	.63	1.Ø3	1.83
Final ACK	.41	.49	.73	1.13	1.93
Transport Overhead					
Set-up	.29	.37	.61	1.Ø1	1.81
Header	.35	.35	.35	.35	.35
Final Block	.23	.23	.23	.23	.23
Session Overhead					
Set-up	.63	.71	.95	1.35	2.15
Total Transmission Time	61.22	61.64	8Ø.1Ø	117.4Ø	192.48
% Overhead	17.5	18.4	53.9	125	269

Figure 4-5

Network Loading vs. PSDN Throughput

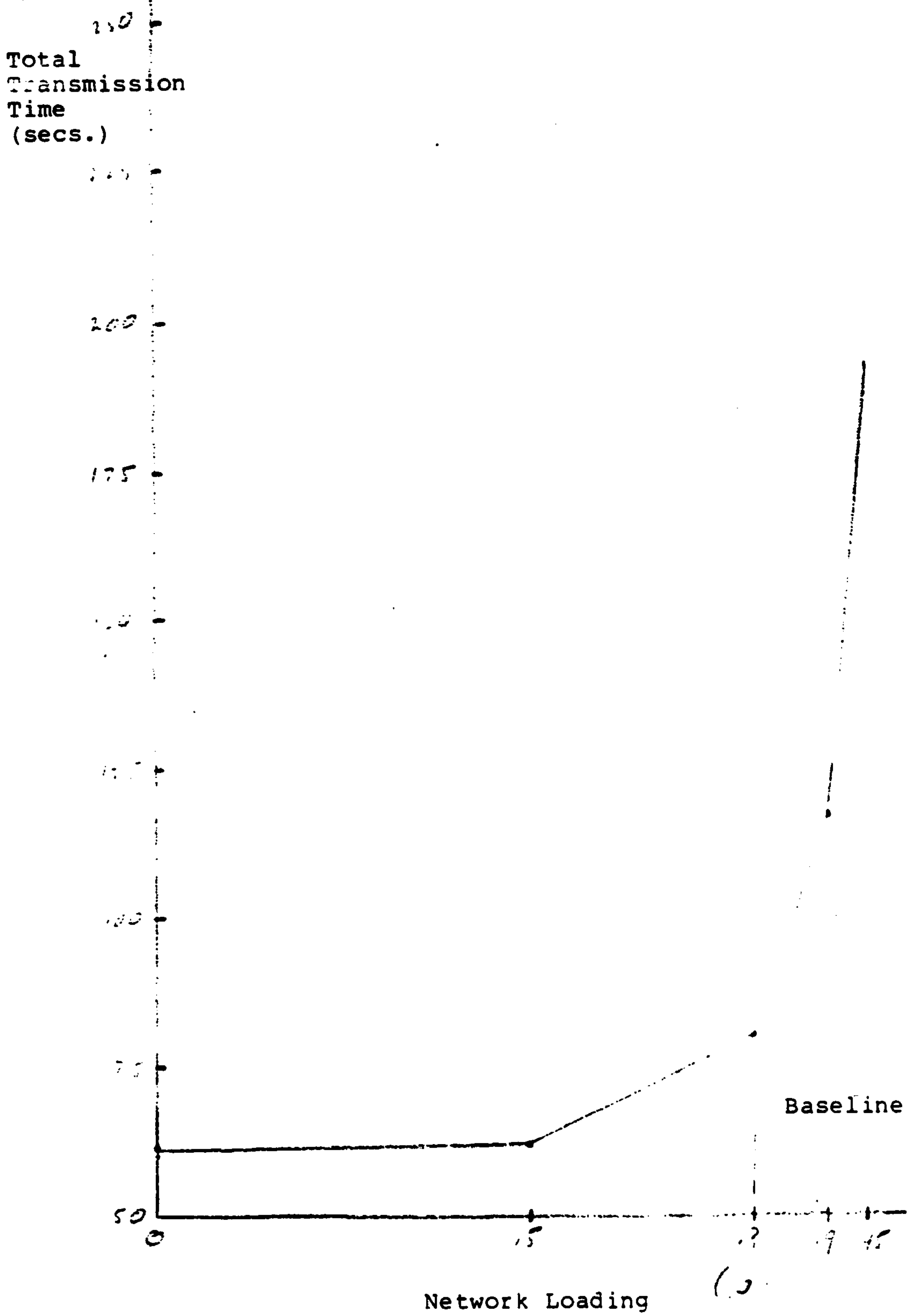


Figure 4-5 shows graphically the effect of network loading on Group 4 throughput.

4.1.4.2 Number of Nodes

In addition to 5 network nodes, 1, 2, 3, 8, and 10 were used. Table 4-13 summarizes the throughput calculations for the various numbers of nodes. For the larger number of nodes the delay in transmitting the packets becomes large, which affects the delay due window halts, and to some extent the time required to set up Network, Transport, and Session protocols. For 1, 2, or 3 nodes there is very little effect on throughput, primarily because the window causes very few halts.

Figure 4-6 shows graphically the effect of the number of network nodes on Group 4 throughput.

4.1.4.3 Number of Satellite Links

The baseline system used all terrestrial links, with an assumed propagation delay of 10 milliseconds. If satellite links are used between network nodes the propagation delay will increase to about 250 milliseconds per link. In addition to the baseline system having no satellite links, throughput was calculated for 1 and 4 of the 4 links being satellite links. Table 4-14 summarizes the calculations of throughput for 0, 1, and all 4 links using satellites. Even one satellite link decreases throughput by a large amount, primarily due to window halts. Having all satellite links leads to unacceptable throughput rates.

Figure 4-7 shows the effect of using satellite links on Group 4

Table 4-13

Throughput Calculation Summary

Packet Switching Data Network

Number of Nodes	1	2	3	5	8	10
Basic FAX Transmission	52.08	52.08	52.08	52.08	52.08	52.08
Link Overhead						
Header	2.45	2.45	2.45	2.45	2.45	2.45
Stuffing Bits	.92	.92	.92	.92	.92	.92
Source Error Retrans.	1.40	1.40	1.40	1.40	1.40	1.40
Sink Error Retrans.	.50	.50	.50	.50	.50	.50
Set-up	.02	.02	.02	.02	.02	.02
Network Overhead						
Header	1.63	1.63	1.63	1.63	1.63	1.63
Window Halts	-	-	1.08	17.60	60.08	72.37
Link Error Retrans.	-	-	-	-	-	
Set-up	.10	.23	.41	.63	1.05	1.27
Final ACK	.15	.29	.44	.73	1.15	1.44
Transport Overhead						
Set-up	.10	.23	.35	.61	.98	1.24
Header	.35	.35	.35	.35	.35	.35
Final Block	.23	.23	.23	.23	.23	.23
Session Overhead						
Set-up	.35	.50	.65	.95	1.39	1.69
Total Transmission Time	60.28	60.83	62.51	80.10	124.23	137.59
%Overhead	15.7	16.8	20.00	53.8	138.5	164.2

Figure 4-6

Number of Nodes vs. PSDN Throughput

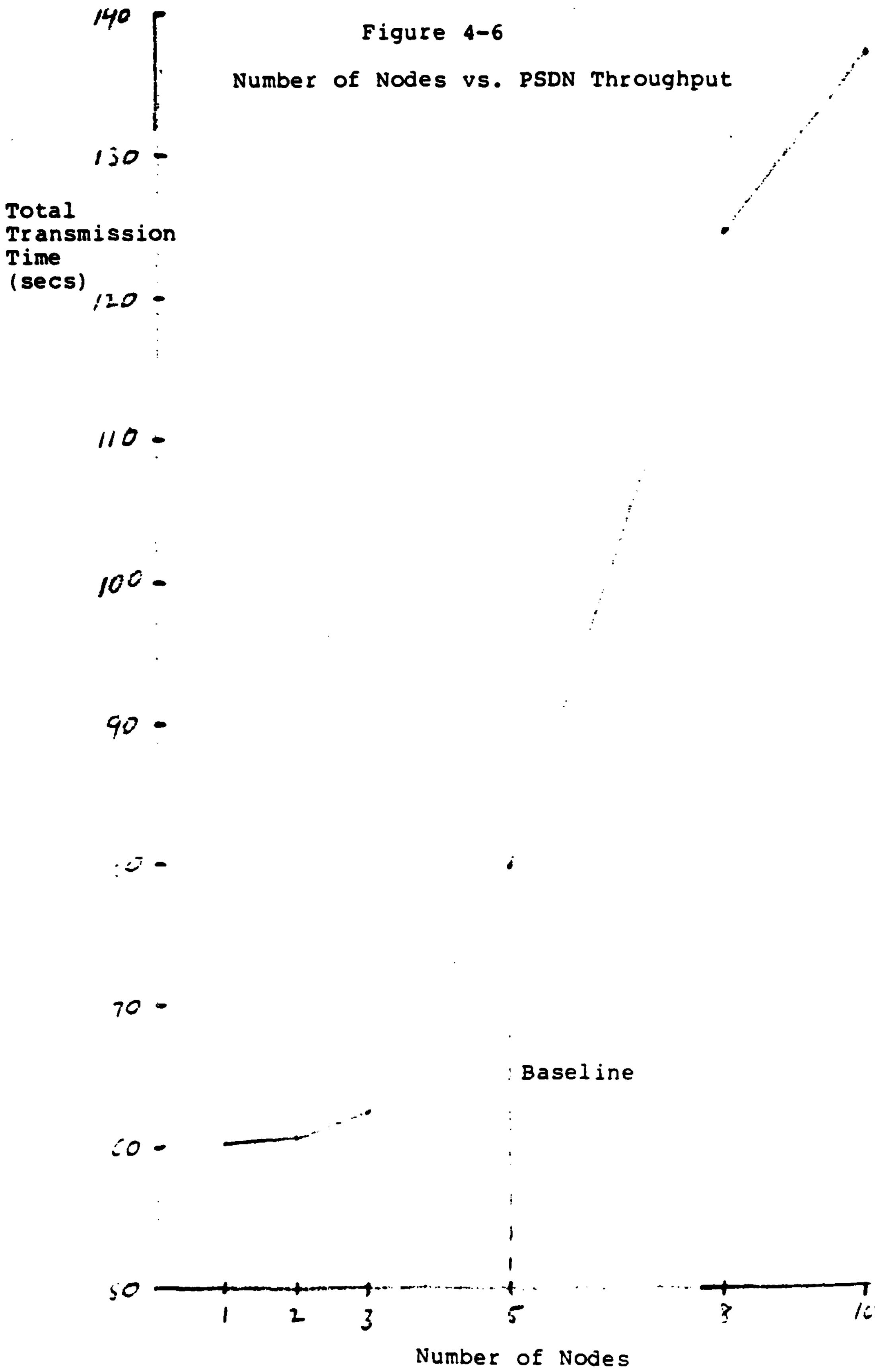


Table 4-14

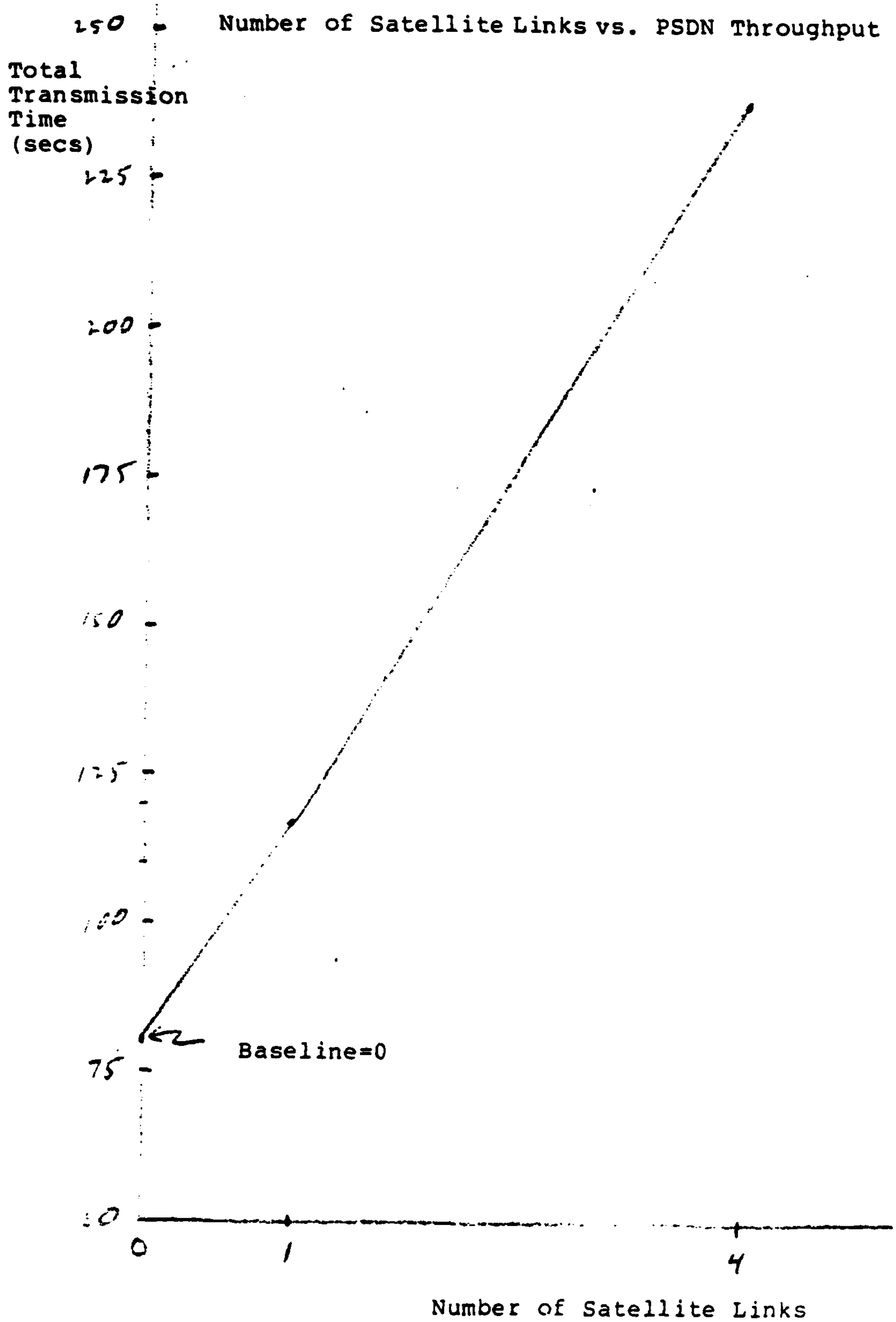
Throughput Calculation Summary

Packet Switching Data Network

Number of Satellite Links	Ø	1	4
Basic FAX Transmission	52.Ø8	52.Ø8	52.Ø8
Link Overhead			
Header	2.45	2.45	2.45
Stuffing Bits	.92	.92	.92
Source Error Retrans.	1.4Ø	1.4Ø	1.4Ø
Sink Error Retrans.	.5Ø	.5Ø	.5Ø
Set-up	.Ø2	.Ø2	.Ø2
Network Overhead			
Header	1.63	1.63	1.63
Window Halts	17.6Ø	52.32	168.22
Link Error Retrans.	-	-	-
Set-up	.63	1.11	2.55
Final ACK	.73	1.21	2.65
Transport Overhead			
Set-up	.61	1.Ø9	2.53
Header	.35	.35	.35
Final Block	.23	.23	.23
Session Overhead			
Set-up	.95	1.43	2.87
Total Transmission Time	8Ø.1Ø	116.74	238.4Ø
% Overhead	53.8	124.2	357.8

Figure 4-7

Number of Satellite Links vs. PSDN Throughput



throughput.

4.1.4.4 Network Window

A network window of 6 was used for the baseline calculation, which gave reasonable results for the other conditions of the baseline system. In addition, network windows of 4, 5, 8, and 10 were used for calculating throughput. Table 4-15 summarizes these calculations. Only the window halt time is affected by the network window. Throughput decreases for smaller windows and increases somewhat for larger windows. Of course increasing the window would dramatically increase throughput in those cases that increase round-trip delay, such as high network loading, large number of nodes, and satellite links.

Figure 4-8 shows the effect of the network window on Group 4 throughput.

4.1.4.5 Packet Size

The baseline system used a packet size of 128 bytes, which is what TELENET currently uses. It might be expected that using a larger packet would improve throughput because of the reduced header overhead at the Network level, and the fact that a given window size allows for more data to be outstanding thereby reducing halts. Calculations were also made for packet sizes of 256 and 512 bytes, and are summarized in Table 4-16. While there is some improvement in Link and Network header overhead, and in window halts, this is to some extent offset by increases in error retransmission overhead, since each detected error requires a much longer retransmission. Also the set-up overhead of Network, Transport, and Session protocols is greater because a larger

Table 4-15

Throughput Calculation Summary

Packet Switching Data Network

Network Window	4	5	6	8	10
Basic FAX Transmission	52.08	52.08	52.08	52.08	52.08
Link Overhead					
Header	2.45	2.45	2.45	2.45	2.45
Stuffing Bits	.92	.92	.92	.92	.92
Source Error Retrans.	1.40	1.40	1.40	1.40	1.40
Sink Error Retrans.	.50	.50	.50	.50	.50
Set-up	.02	.02	.02	.02	.02
Network Overhead					
Header	1.63	1.63	1.63	1.63	1.63
Window Halts	49.39	29.83	17.60	4.16	.14
Link Error Retrans.	-	-	-	-	-
Set-up	.63	.63	.63	.63	.63
Final ACK	.73	.73	.73	.73	.73
Transport Overhead					
Set-up	.61	.61	.61	.61	.61
Header	.35	.35	.35	.35	.35
Final Block	.23	.23	.23	.23	.23
Session Overhead					
Set-up	.95	.95	.95	.95	.95
Total Transmission Time	111.89	92.33	80.10	66.66	62.64
% Overhead	114.8	77.3	53.8	28.0	20.3

Figure 4-8

Network Window vs. PSDN Throughput

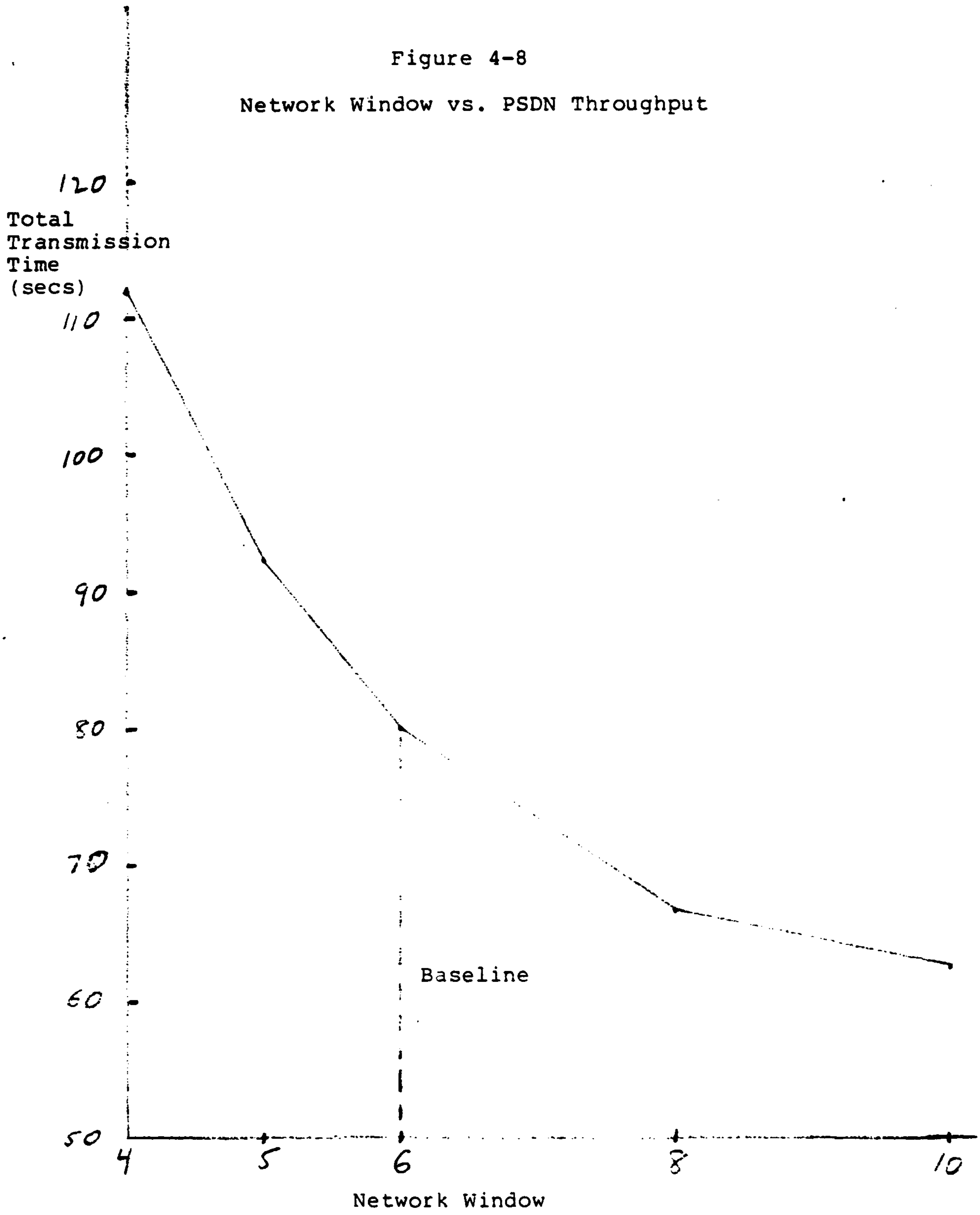


Table 4-16

Throughput Calculation Summary

Packet Switching Data Network

Packet Size (bytes)	128	256	512
Basic FAX Transmission	52.08	52.08	52.08
Link Overhead			
Header	2.45	1.22	.61
Stuffing Bits	.92	.86	.85
Source Error Retrans.	1.40	2.48	4.86
Sink Error Retrans.	.50	.93	1.82
Set-up	.02	.02	.02
Network Overhead			
Header	1.63	.81	.41
Window Halts	17.60	11.47	8.17
Link Error Retrans.	-	.11	.22
Set-up	.63	.93	1.53
Final ACK	.73	1.22	2.18
Transport Overhead			
Set-up	.61	.91	1.50
Header	.35	.35	.35
Final Block	.23	.23	.23
Session Overhead			
Set-up	.95	1.25	1.84
Total Transmission Time	80.10	74.87	76.67
% Overhead	53.8	43.8	47.2

packet is used to carry a small amount of information. The net result is that increasing packet size does not dramatically improve throughput. As can be seen in Figure 4-9, going from 256 to 512 bytes actually decreases throughput. It is concluded that packet size is not a sensitive factor in determining Group 4 throughput.

4.1.4.6 Error Rates

The baseline system assumed that the BER on each local link was 10^{-5}, and on each network link was 10^{-6}. Both types of errors were increased by an order of magnitude and decreased by an order of magnitude in order to establish the sensitivity of the assumed error rate.

The results are shown in Table 4-17. Only the times required for Source Error Retransmission and Link Error Retransmission change with error rate. The delay due to Link Error Retransmission is negligable except for a BER of 10^{-5}. The primay effect of these errors is to cause an increase in the window halt time for those packets that had to be retransmitted due to errors. It was assumed that packets that were retransmitted by nodes due to errors have a higher priority than normal packets, and therfore do not have to experience the queue delay.

The results of the error sensitivity analysis are shown in Figure 4-10. Decreasing the error rates by an order of magnitude does not increase throughput significantly, while increasing the error rate by a factor of 10 does have a significant impact.

Figure 4-9

Packet Size vs. PSDN Throughput

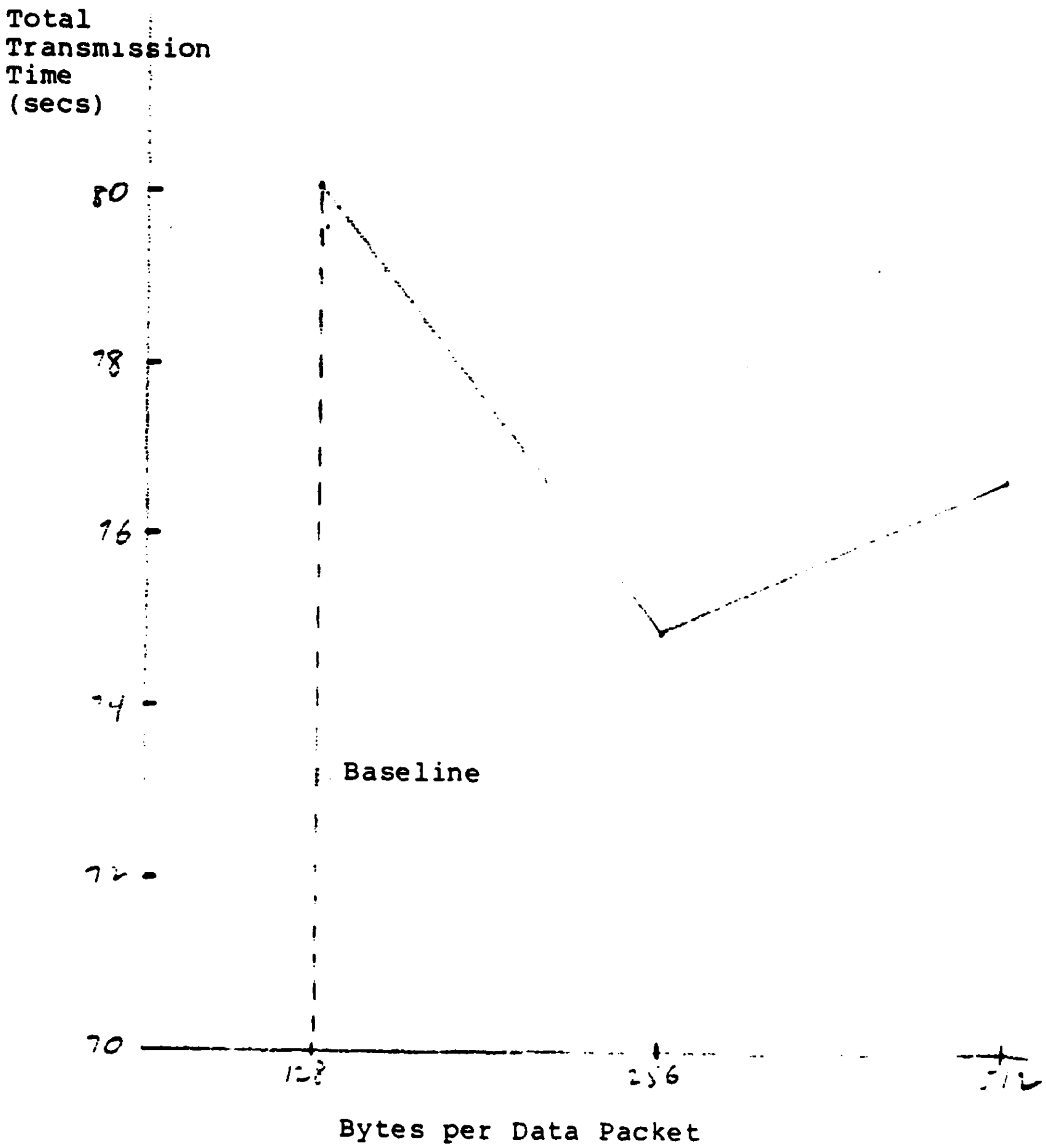


Table 4-17

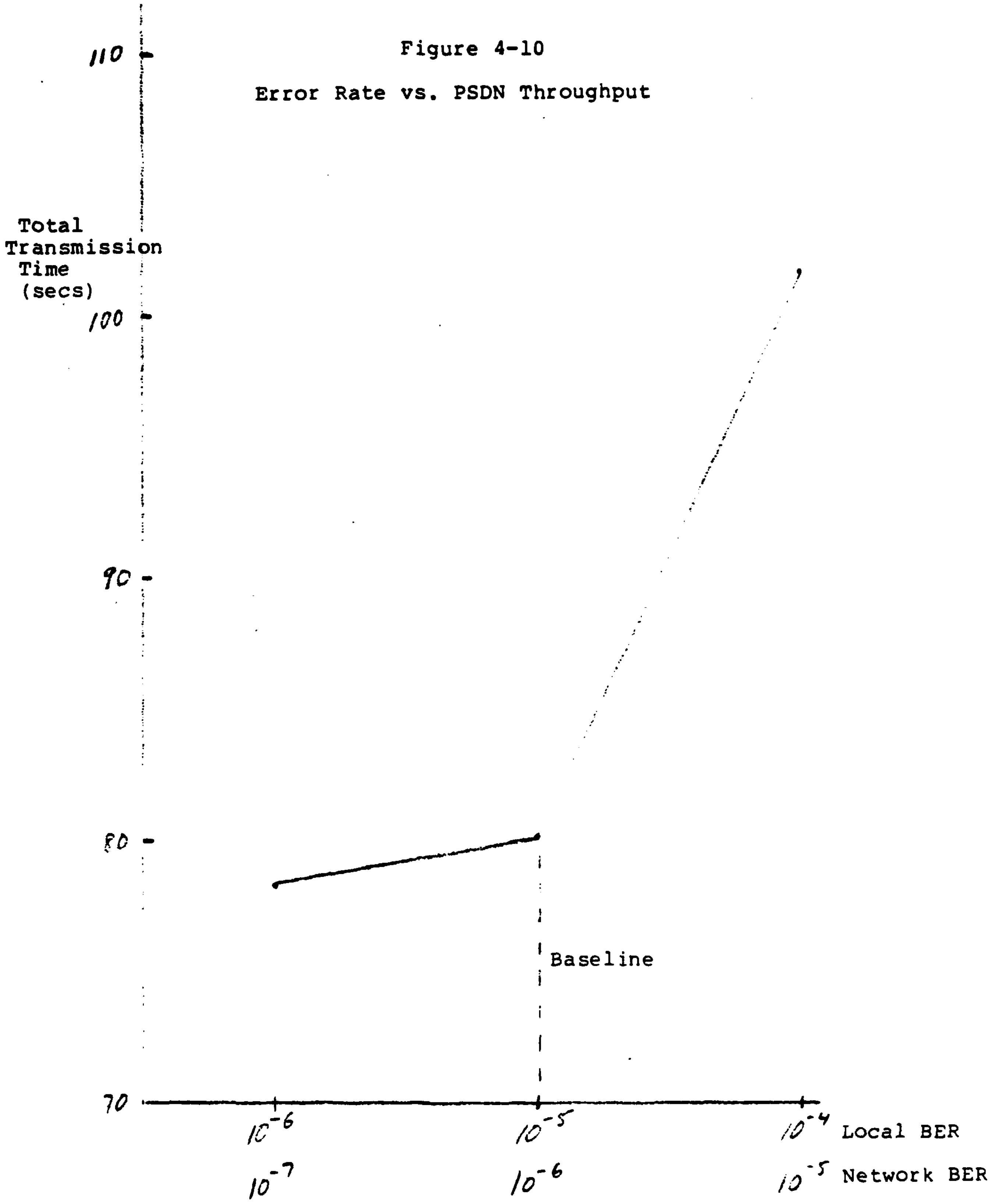
Throughput Calculation Summary

Packet Switching Data Network

	Local Link	10^{-6}	10^{-5}	10^{-4}
Raw Error Rate	Network Link	10^{-7}	10^{-6}	10^{-5}
Basic FAX Transmission		52.08	52.08	52.08
Link Overhead				
Header		2.45	2.45	2.45
Stuffing Bits		.92	.92	.92
Source Error Retrans.		.14	1.40	17.55
Sink Error Retrans.			.50	.50
Set-up		.02	.02	.02
Network Overhead				
Header		1.63	1.63	1.63
Window Halt		17.60	17.60	17.60
Link Error Retrans.				5.39
Set-up		.63	.63	.63
Final ACK		.73	.73	.73
Transport Overhead				
Set-up		.61	.61	.61
Header		.35	.35	.35
Final Block		.23	.23	.23
Session Overhead				
Set-up		.95	.95	.95
Total Transmission Time		78.34	80.10	101.64
% Overhead		50.4	53.8	95.2

Figure 4-10

Error Rate vs. PSDN Throughput



4.1.4.7 Length of FAX Page

The baseline system used a compressed FAX message of 500,000 bits. In addition, message lengths of 300,000, 400,000, 600,000, and 700,000 bits were used. Increasing the length of the message also increases most of the overhead proportionately, except for the set-up and tear-down of the protocols. The summary of the throughput calculations is shown in Table 4-18. Notice that the percent overhead decreases slightly as the message length increases, owing to the reduced proportion of the fixed set-up overhead. The results are summarized in Figure 4-11.

Table 4-18

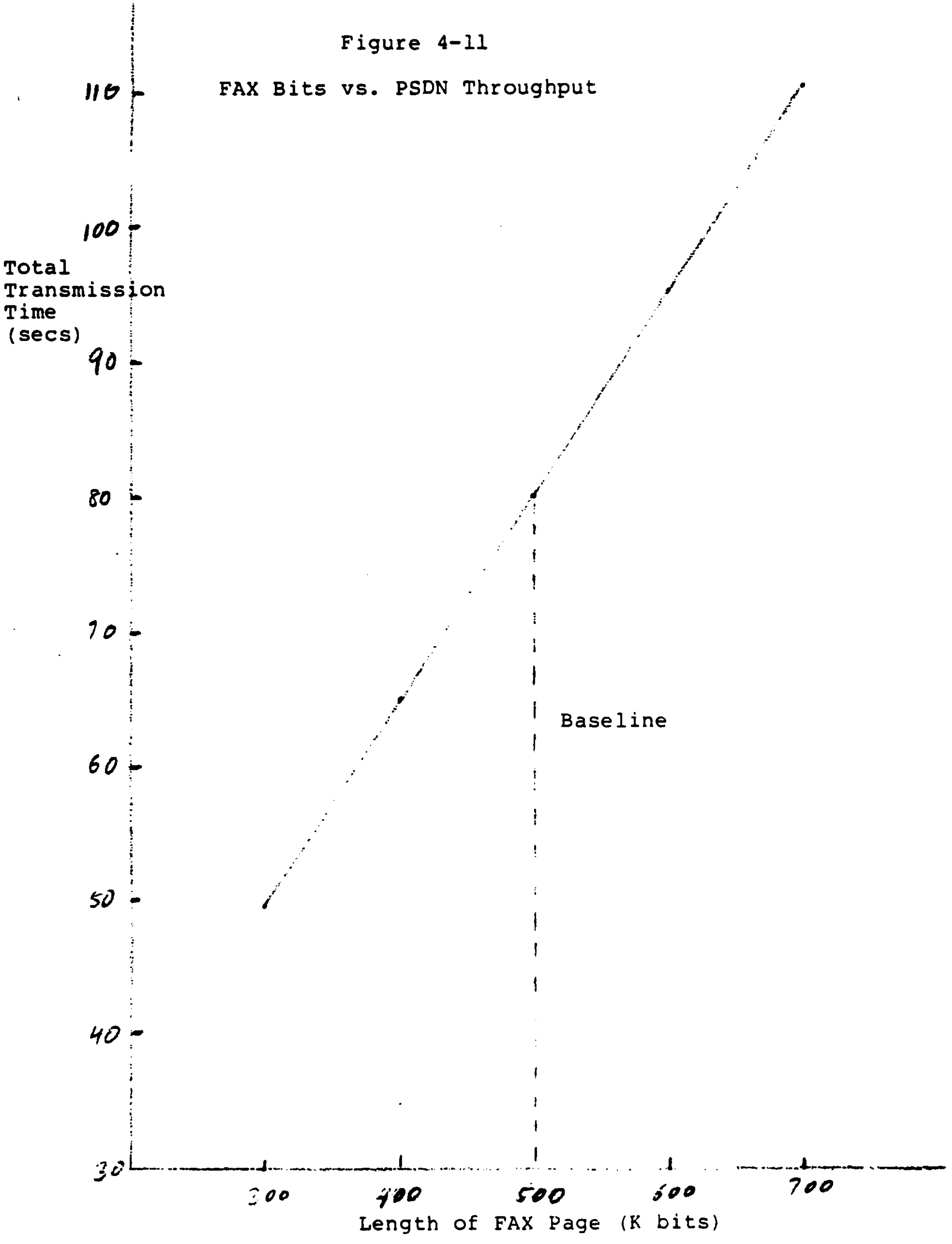
Throughput Calculation Summary

Packet Switching Data Network

Bits in FAX Image	300k	400k	500k	600k	700k
Basic FAX Transmission	31.25	41.67	52.08	62.50	72.92
Link Overhead					
Header	1.47	1.96	2.45	2.93	3.42
Stuffing Bits	.55	.73	.92	1.10	1.28
Source Error Retrans.	.83	1.17	1.40	1.64	1.99
Sink Error Retrans.	.50	.50	.50	.50	.50
Set-up	.02	.02	.02	.02	.02
Network Overhead					
Header	.98	1.30	1.63	1.95	2.28
Window Halts	10.55	14.08	17.60	21.10	24.62
Link Error Retrans.	-	-	-	-	-
Set-up	.63	.63	.63	.63	.63
Final ACK	.73	.73	.73	.73	.73
Transport Overhead					
Set-up	.61	.61	.61	.61	.61
Header	.20	.35	.35	.47	.47
Final Block	.23	.23	.23	.23	.23
Session Overhead					
Set-up	.95	.95	.95	.95	.95
Total Transmission Time	49.50	64.93	80.10	95.36	110.65
% Overhead	58.4	55.8	53.8	52.6	51.7

Figure 4-11

FAX Bits vs. PSDN Throughput



4.2 Circuit Switched Data Network (CSDN)

4.2.1 Methodology

Again a baseline system is assumed, and the time required to transmit a single page is calculated. In addition, variations of certain parameters are used, one at a time, to show the sensitivity of throughput to the assumptions made.

4.2.2 Assumptions

In the CSDN, the user obtains a high-speed data circuit directly from source to sink. The parameters of the AT&T Circuit Switched Digital Capability (CSDC) will be used. This includes duplex transmission at a rate of 56,000 bits per second, with a bit error rate of 10^{-6}. Duplex operation over the local link is obtained by accumulating 3 msec bursts and transmitting at a rate above 112,000 bits per second. The result is that a 2 msec delay is incurred for end-to-end transmission. When the circuit is first set up, it operates in a voice mode. To convert to data mode takes approximately 3.3 sec.

The other assumptions used for PSDN are also used here, except that Network Loading and Window are not applicable to CSDN, and the processing delay is only applicable to the terminals. Figure 4-12 shows the CSDN to be analyzed.

4.2.3 Baseline Throughput Calculations

The time required to transmit the FAX image of 500,000 bits at 56,000 bits per second is 8.93 seconds. The overhead for each level of protocol will be calculated in the following sections.

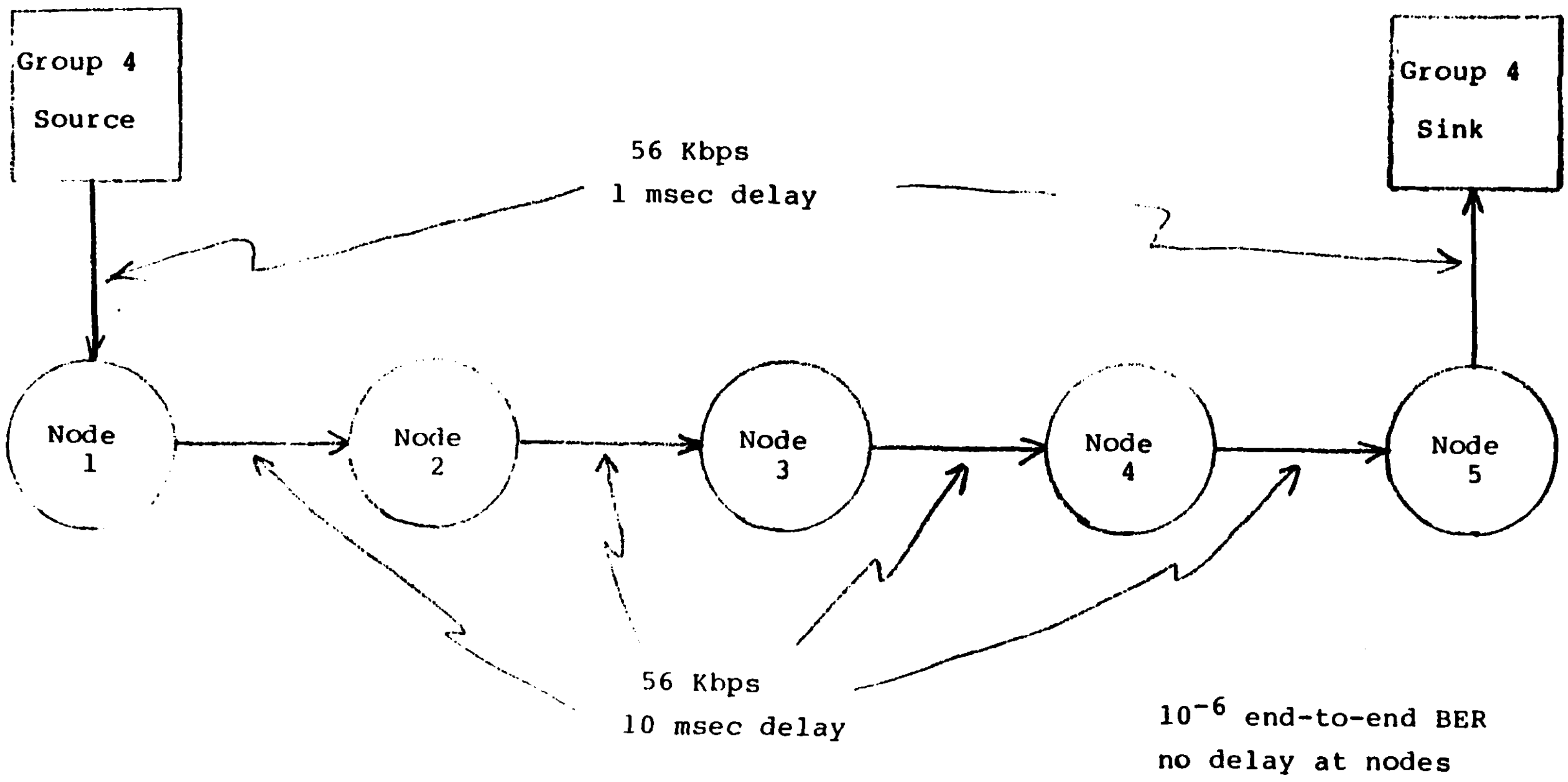


Figure 4-12
CSDN BASELINE NETWORK

4.2.3.1 Physical/Modem Overhead

There is no overhead at this level that contributes to message throughput.

4.2.3.2 Link Overhead

The link protocol is used as in PSDN, except that it is the terminals that exchange information. Again there are 18 stuffing bits per packet, and 489 data packets, which requires $\frac{489x18}{56,000}$=0.16 sec. to transmit. The header is 6 bytes, which will take $\frac{6x8x489}{56,000}$=0.42 sec. to transmit.

The overall end-to-end error rate is 10^{-6}. This means that the probability of packet error is 0.001122, and that about 0.001122 x 489= 0.5 packets can be expected to be received in error. The round trip delay, after a packet is transmitted until an ACK is received can be calculated as:

Local link propagation delay 4x1 msec	4
Network link propagation delay 8x10 msec	80
Sink procesing time	10
ACK transmission time	1
Total	95 msec

During this time, 4.75 packets of 20 msec duration have been transmitted. In addition, the error packet and the one following were transmitted and must be retransmitted. Therefore 6.75 packets must be retransmitted for each packet that is in error, and an average of 3.5 packets must be retransmitted per page, which will take 70 msec, or 0.07

seconds.

The link is set up by transmitting a supervisory message of 6 bytes which takes only 2 msec at each end. To this must be added the two-way delay, 94 msec, which gives 98 msec, or 0.10 sec to set up the link.

To change the link from voice to data transmission, a 3.3 sec delay is incurred, which is added overhead.

4.2.3.3 Network Overhead

The functions that the Network Protocol provide are not required for CSDN, but the protocol must be set up to follow the layered structure of protocols shown in Figure 3-3. Setting up the Network protocol requires the two-way transmission of a 25-byte message. Transmission at each end requires 5 msec, so the total time to set-up the protocol is 104 msec, or 0.10 sec. In addition, the Network protocol must be torn down after the transmission. This requires the return of the final ACK, which will take about the round trip delay, or an additional 0.10 seconds.

The Network header is reduced to only two bytes for use with the CSDN. See S.70, Figure 1/S/70 and paragraph 3.3.3.2. Therefore 2x489 = 978 bytes must be transmitted during a page, which takes 140 msec, or 0.14 sec.

4.2.3.4 Transport Overhead

The Transport Level is defined by S.70 as with the PSDN. The Set-up is accomplished by a 10-byte message each way. This takes only 3 msec at each end, plus the round-trip delay of 94 msec, or 100 msec.

Therefore set-up takes 0.10 sec.

Again, a 512-byte transport block minimizes the transport overhead. This requires 368 header bytes, which takes 53 msec, or 0.05 sec to transmit. The final half-block has 256 bytes, which takes 37 msec to transmit, or 0.04 sec.

4.2.3.5 Session Overhead

The Session Level is defined by S.62. The Session is started by transmitting both ways a 96-byte message, which takes 15 msec in each direction. Added to the 94 msec two-way delay gives a total of 124 msec, or 0.12 sec.

4.2.3.6 Presentation and Application Overhead

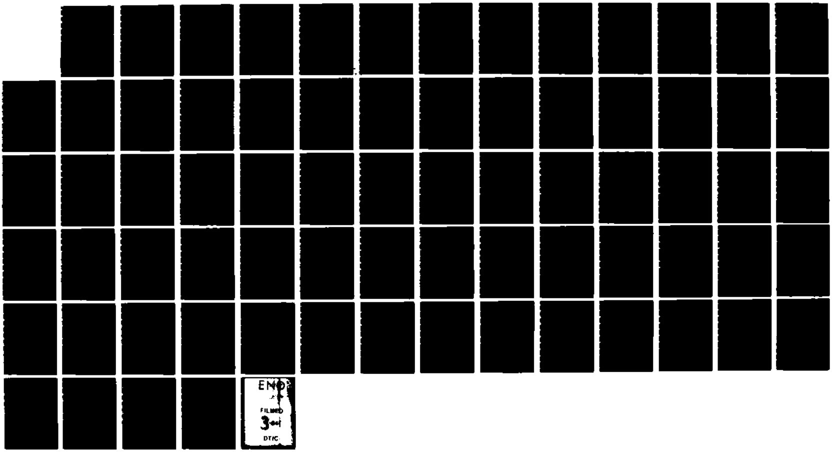
As with PSDN, it does not apppear that there well be significant overhead from these protocol levels.

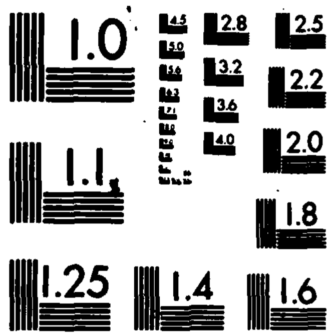
4.2.3.7 Summary of CSDN Baseline Throughput

Table 4-19 summarizes the calculations made for the CSDN throughput. The total transmission time, 13.63 seconds, is much shorter than the 80.10 seconds for PSDN. The total overhead is 52.6 %, the largest part of which is the time required to change from voice to data transmission. For multi-page transmission, this overhead would be divided among the number of pages in the transmission, so its effect would be greatly reduced.

AD-A137 613 GROUP 4 FACSIMILE THROUGHPUT ANALYSIS(U) DELTA INFORMATION SYSTEMS INC JENKINTOWN PA R SCHAPHORST ET AL. 19 SEP 83 NCS-TIB-83-6 2/2

UNCLASSIFIED DCA100-82-C-0072 F/G 17/2 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Table 4-19

Throughput Calculation Summary

Circuit Switching Data Network

Baseline System	
Basic FAX Transmission	8.93
Link Overhead	
Header	.42
Stuffing Bits	.16
Error Retrans.	.07
Convert to Data Mode	3.30
Set-up	.10
Network Overhead	
Header	.14
Set-up	.10
Final ACK	.10
Transport Overhead	
Set-up	.10
Header	.05
Final Block	.04
Session Overhead	
Set-up	.12
Total Transmission Time	13.63
% Overhead	52.6

4.2.4 Sensitivity of Throughput to Baseline Assumptions

In order to determine the sensitivity of the results presented in Section 4.2.3 to the assumptions used in the baseline system, a selected set of baseline parameters were varied one at a time and the throughput calculated. The following sections discuss the variations used and the results obtained.

4.2.4.1 Number of Nodes

In addition to 5 network nodes, 1, 2, 3, 8 and 10 nodes were used. Table 4-20 summarizes the throughput calculations for various numbers of nodes. The primary effect is to vary the round-trip time and therefore to vary the set-up times. As seen in Figure 4-13, the throughput does not vary greatly with the number of nodes in the CSDN.

4.2.4.2 Number of Satellite Links

If some of the links use satellite transmission, the propagation delay increases from 10 to 250 msec. This has a similar effect to increasing the number of nodes, but it has a greater magnitude, as seen in Table 4-21, which summarizes the throughput calculations. Using all satellite links prohibitively increases transmission time, as shown in Figure 4-14, although the throughput is still much better than the PSDN.

4.2.4.3 Packet Size

Increasing the packet size from 128 bytes to 256 or 512 bytes gives the results shown in Table 4-22. In this case, the increased packet size definitely reduces the overhead, because the increase in the time

Table 4-20

Throughput Calculation Summary

Circuit Switching Data Network

Number of Nodes	1	2	3	5	8	10
Basic FAX Transmission	8.93	8.93	8.93	8.93	8.93	8.93
Link Overhead						
Header	.42	.42	.42	.42	.42	.42
Stuffing Bits	.16	.16	.16	.16	.16	.16
Error Retrans.	.03	.04	.05	.07	.10	.12
Convert to Data Mode	3.30	3.30	3.30	3.30	3.30	3.30
Set-up	.02	.04	.06	.10	.16	.20
Network Overhead						
Header	.14	.14	.14	.14	.14	.14
Set-up	.02	.04	.06	.10	.16	.20
Final ACK	.02	.04	.06	.10	.16	.20
Transport Overhead						
Set-up	.02	.04	.06	.10	.16	.20
Header	.05	.05	.05	.05	.05	.05
Final Block	.04	.04	.04	.04	.04	.04
Session Overhead						
Set-up	.04	.06	.08	.12	.18	.22
Total Transmission Time	13.19	13.30	13.41	13.63	13.96	14.18
% Overhead	47.7	48.9	50.2	52.6	56.3	58.8

Figure 4-13

Number of Nodes vs. CSDN Throughput

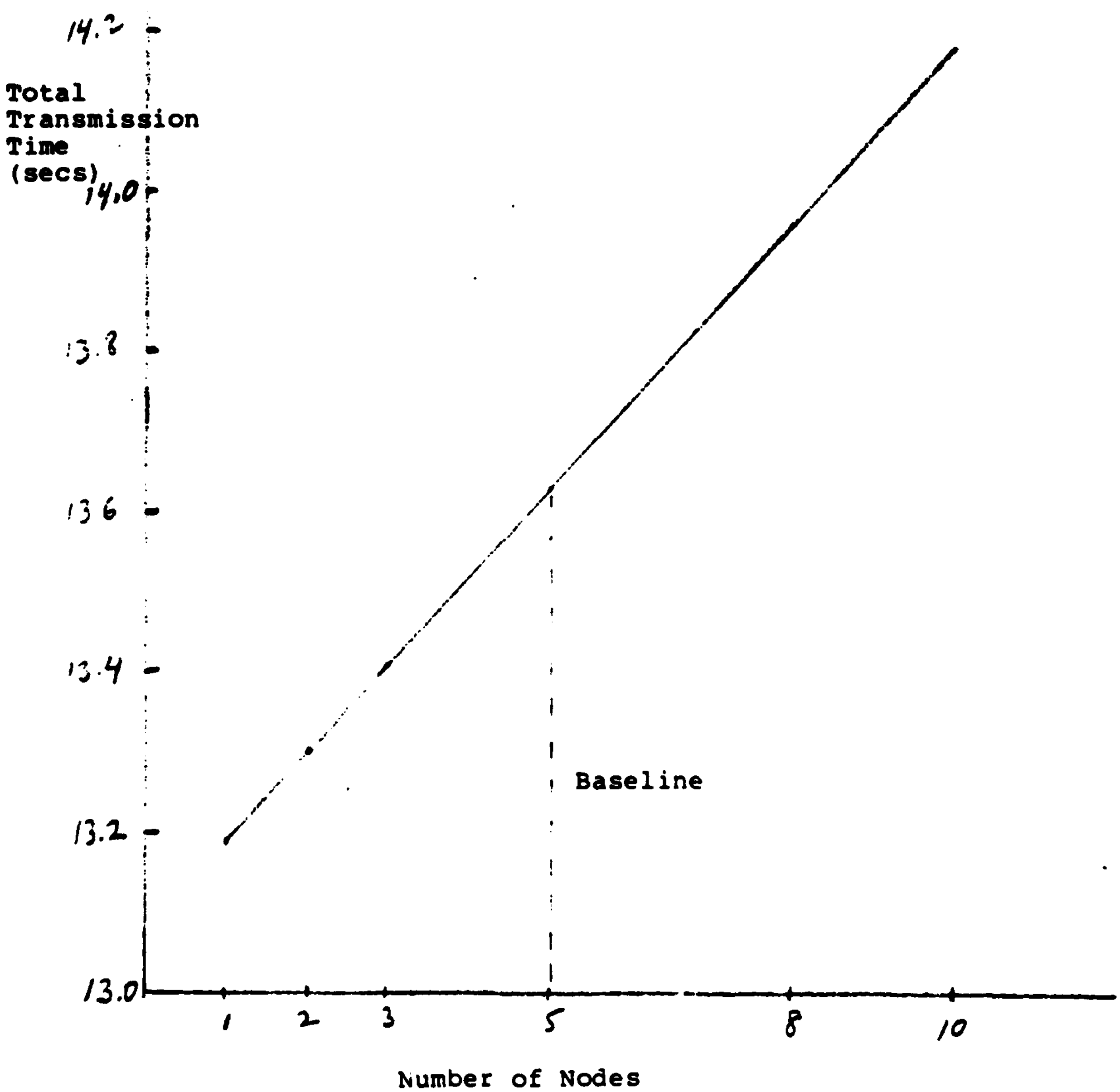


Table 4-21

Throughput Calculation Summary

Circuit Switching Data Network

Number of Satellite Links	0	1	4
Basic FAX Transmission	8.93	8.93	8.93
Link Overhead			
Header	.42	.42	.42
Stuffing Bits	.16	.16	.16
Error Retrans.	.07	.31	1.03
Convert to Data Mode	3.30	3.30	3.30
Set-up	.10	.58	2.02
Network Overhead			
Header	.14	.14	.14
Set-up	.10	.58	2.02
Final ACK	.10	.58	2.02
Transport Overhead			
Set-up	.10	.58	2.02
Header	.05	.05	.05
Final Block	.04	.04	.04
Session Overhead			
Set-up	.12	.60	2.04
Total Transmission Time	13.63	16.27	24.19
% Overhead	52.6	82.2	170.9

Figure 4-14

Number of Satellite Links vs. CSDN Throughput

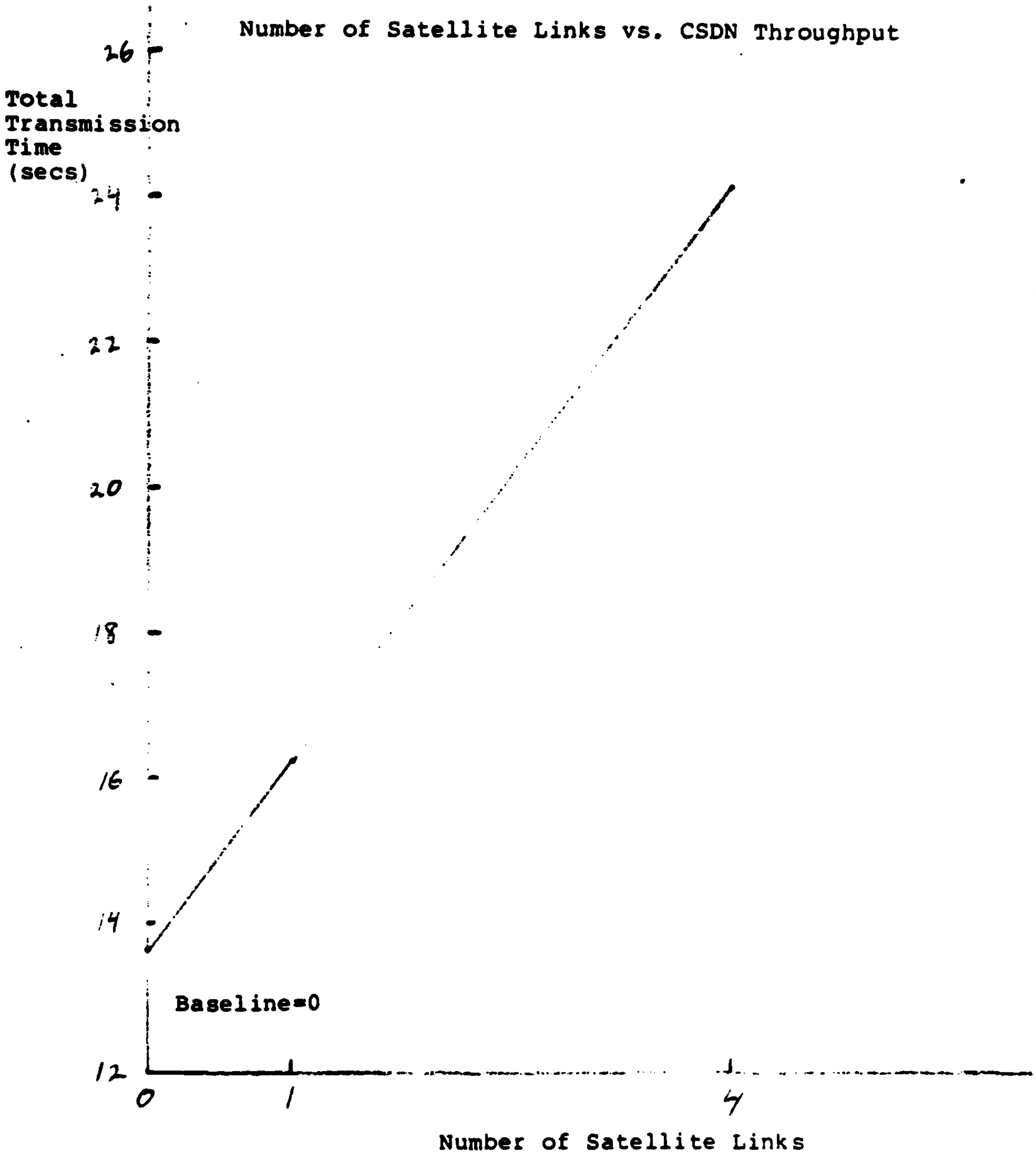


Table 4-22

Throughput Calculation Summary

Circuit Switching Data Network

Bytes per Packet	128	256	512
Basic FAX Transmission	8.93	8.93	8.93
Link Overhead			
Header	.42	.21	.11
Stuffing Bits	.16	.08	.04
Error Retrans.	.07	.09	.13
Convert to Data Mode	3.30	3.30	3.30
Set-up	.10	.10	.10
Network Overhead			
Header	.14	.07	.04
Set-up	.10	.10	.10
Final ACK	.10	.10	.10
Transport Overhead			
Set-up	.10	.10	.10
Header	.05	.05	.05
Final Block	.04	.04	.04
Session Overhead			
Set-up	.12	.12	.12
Total Transmission Time	13.63	13.29	13.16
% Overhead	52.6	48.8	47.4

required to retransmit packets is not great at 56,000 bits/sec. The results are shown graphiclly in Figure 4-15.

4.2.4.4 Error Rate

The baseline end-to-end error rate was assumed to be 10^{-6}. Using 10^{-5} and 10^{-7} BER gives the results shown in Table 4-23. The error rate affects only the time required to retransmit error packets. The throughput does not appear to be very sensitive to error rate, as shown in Figure 4-16.

4.2.4.5 Length of FAX Page

Table 4-24 shows the calculations for various length transmissions, from 300,000 bits to 700,000 bits per FAX page. Notice that the percent overhead does not vary greatly. The results are shown graphically in Figure 4-17.

Figure 4-15

Packet Size vs. CSDN Throughput

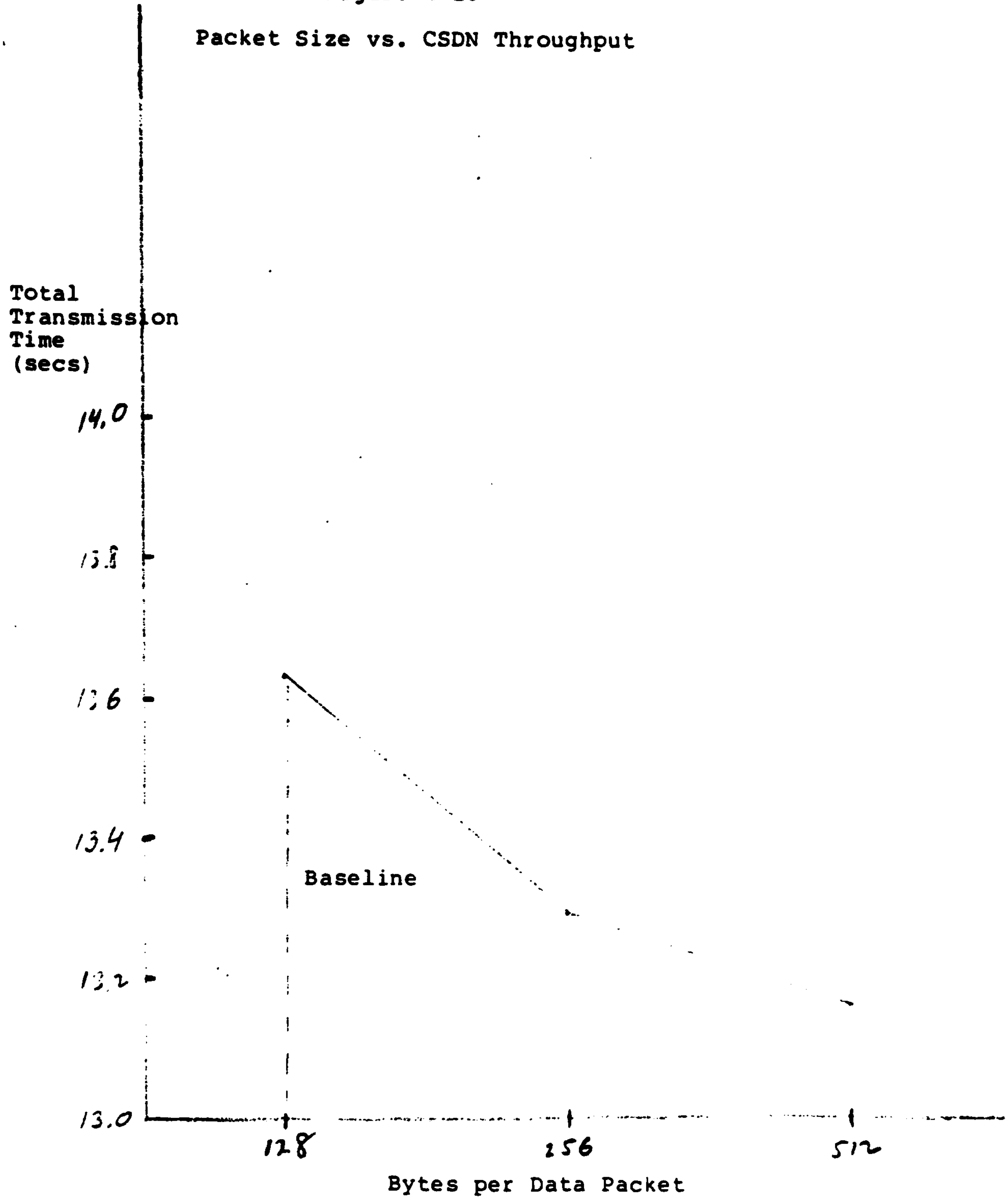


Table 4-23

Throughput Calculation Summary

Circuit Switching Data Network

End-to-end Error Rate	10^{-5}	10^{-6}	10^{-7}
Basic FAX Transmission	8.93	8.93	8.93
Link Overhead			
Header	.42	.42	.42
Stuffing Bits	.16	.16	.16
Error Retrans.	.80	.07	.01
Convert to Data Mode	3.30	3.30	3.30
Set-up	.10	.10	.10
Network Overhead			
Header	.14	.14	.14
Set-up	.10	.10	.10
Final ACK	.10	.10	.10
Transport Overhead			
Set-up	.10	.10	.10
Header	.05	.05	.05
Final Block	.04	.04	.04
Session Overhead			
Set-up	.12	.12	.12
Total Transmission Time	14.16	13.63	13.57
% Overhead	58.6	52.6	52.0

Figure 4-16

Error Rate vs. CSDN Throughput

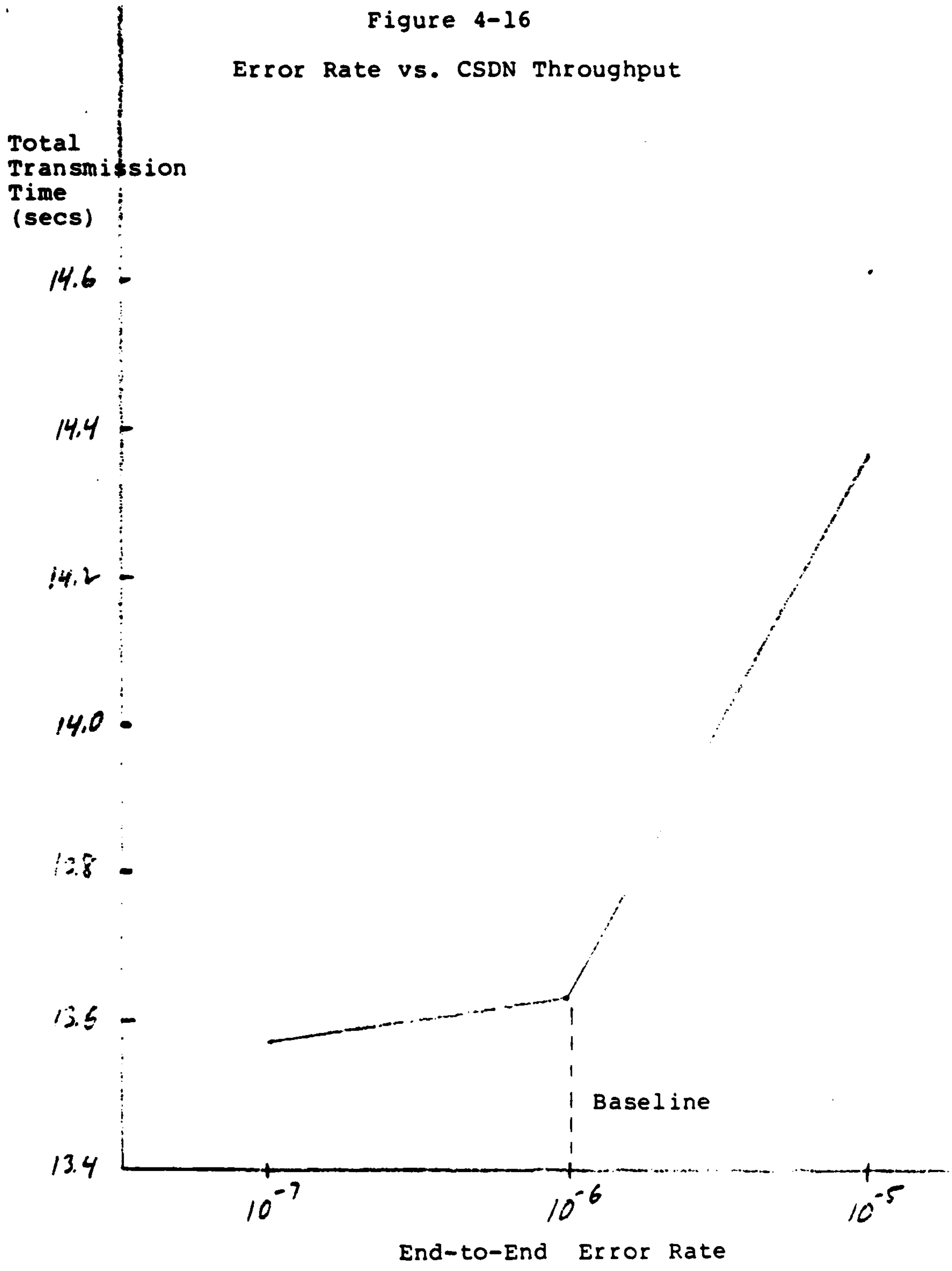


Table 4-24

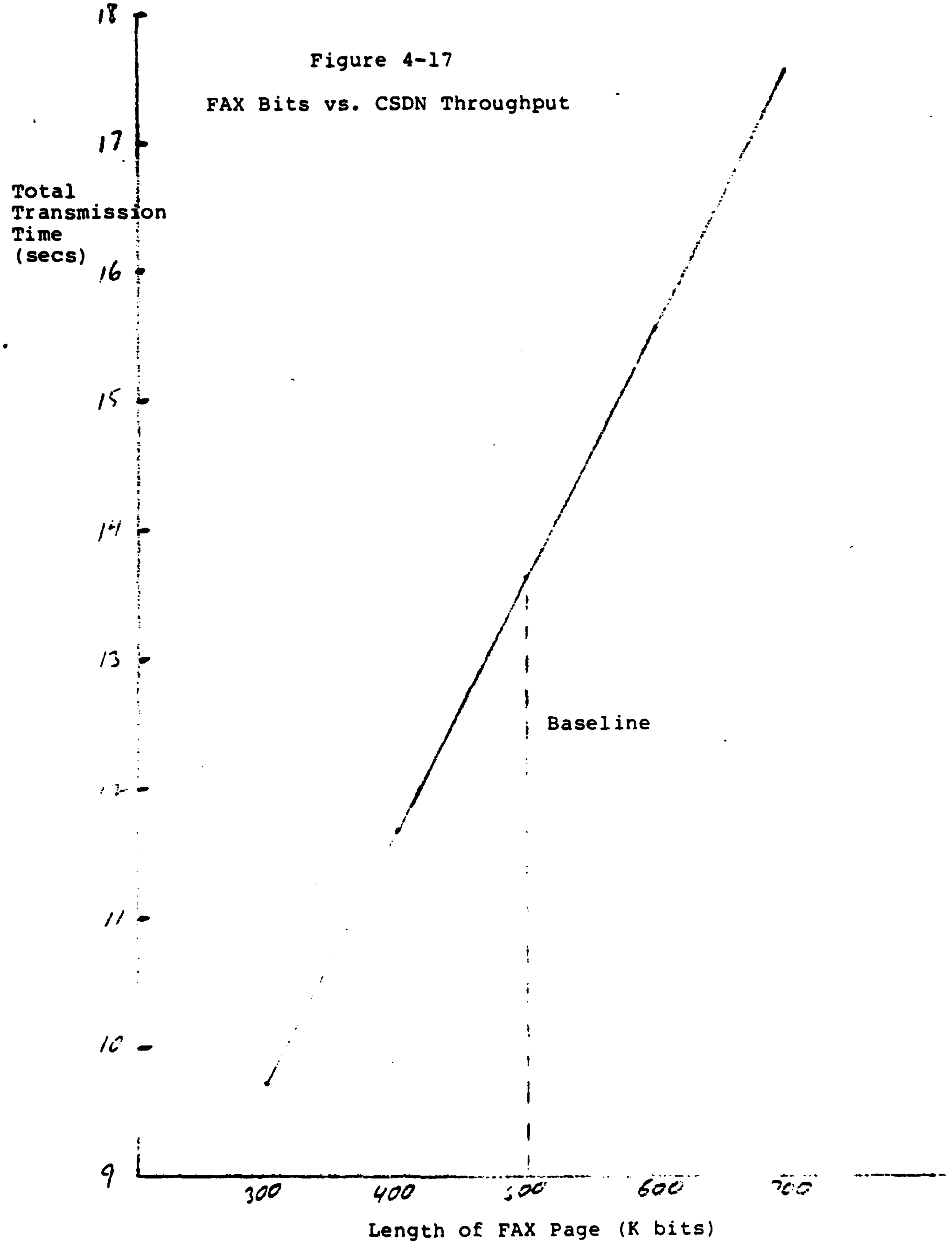
Throughput Calculation Summary

Circuit Switching Data Network

Length of FAX Page Kbits	300	400	500	600	700
Basic FAX Transmission	5.36	7.14	8.93	10.71	12.50
Link Overhead					
Header	.25	.34	.42	.50	.59
Stuffing Bits	.09	.13	.16	.19	.22
Error Retrans.	.04	.06	.07	.09	.10
Convert to Data Mode	3.30	3.30	3.30	3.30	3.30
Set-up	.10	.10	.10	.10	.10
Network Overhead					
Header	.08	.11	.14	.17	.20
Set-up	.10	.10	.10	.10	.10
Final ACK	.10	.10	.10	.10	.10
Transport Overhead					
Set-up	.10	.10	.10	.10	.10
Header	.03	.04	.05	.06	.07
Final Block	.04	.04	.04	.04	.04
Session Overhead					
Set-up	.12	.12	.12	.12	.12
Total Transmission Time	9.71	11.68	13.63	15.58	17.54
% Overhead	81.2	63.6	52.6	45.5	40.3

Figure 4-17

FAX Bits vs. CSDN Throughput



4.3 Public Switched Telephone Network (PSTN)

4.3.1 Methodology

The methodology for the PSTN is exactly the same as for the CSDN. The time required to transmit a single page is calculated for a baseline system. Certain parameters are vaied from the baseline values to determine the sensitivity of throughput to the assumptions.

4.3.2 Assumptions

In the PSTN, the user obtains a normal telephone circuit by dialing the destination. Then operation is exactly as for the CSDN, except that the data rate is lower and the error rate is higher. A data rate of 9600 bits per second will be used here because it appears feasible, and because it is consistent with the 9600 bits/sec. used in the PSDN analysis. In the PSDN analysis a baseline value of 10^{-5} was used for the BER on the 9600 bits/sec circuit. But this was for a relatively short local link betwen the user and the nearest node, without any intervening nodes. Here, because of the longer link lengths, and because of the multiple nodes, an end-to-end BER of 10^{-4} will be assumed. For a network with fewer nodes, appropriate changes in the BER will be used. Figure 4-18 shows the baseline network used for PSTN.

For the PSTN, there is no requirement for switching from voice to data modes.

4.3.3 Baseline Throughput Calculations

The time required to transmit the FAX image of 500,000 bits at 9600 bits per second is 52.08 seconds. The overhead for each level of

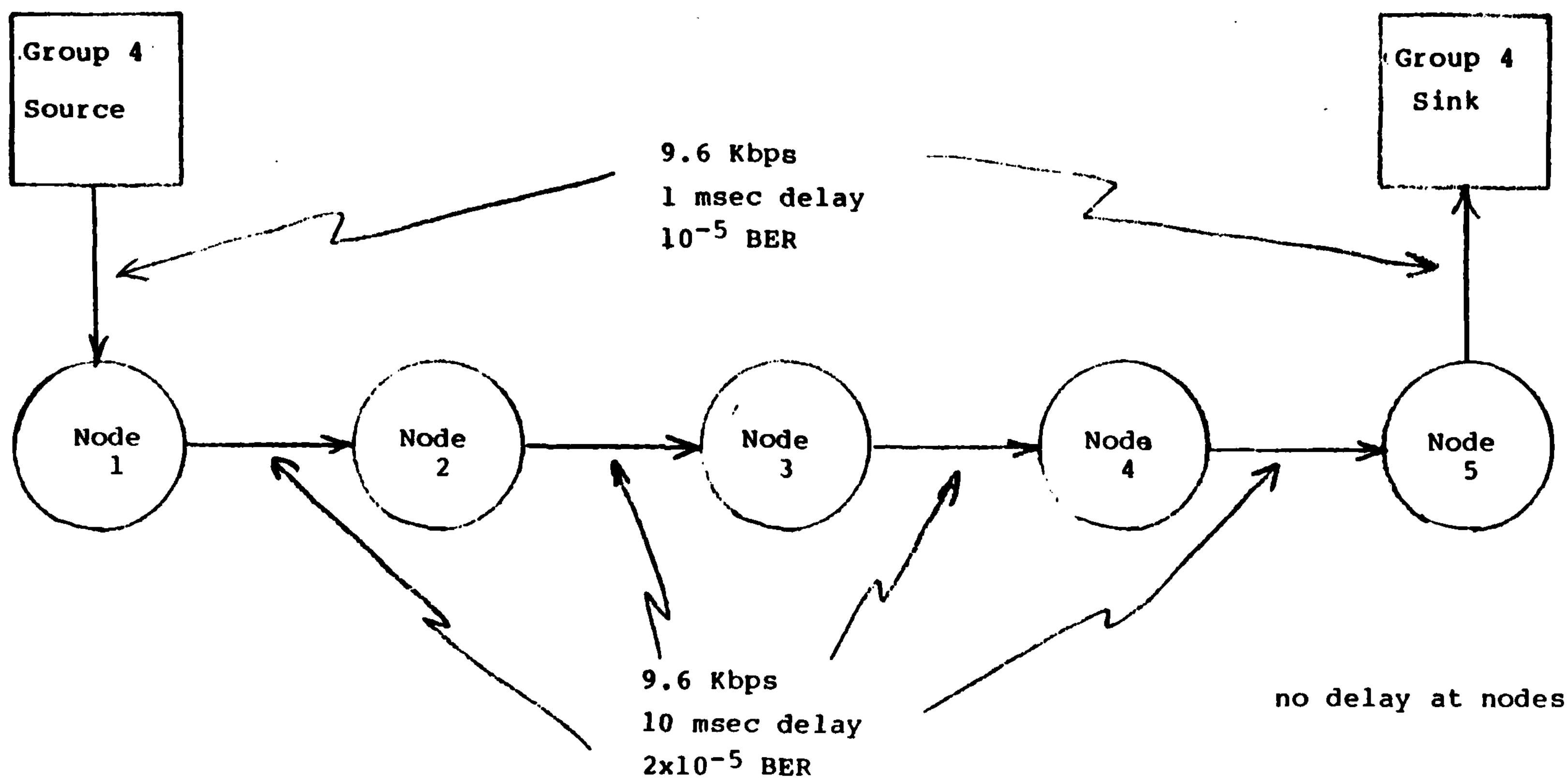


Figure 4-18
PSTN BASELINE NETWORK

protocol will be calculated in the following sections.

4.3.3.1 Physical/Modem Overhead

Again there is no overhead at this level that contributes to message throughput.

4.3.3.2 Link Overhead

The link protocol is used as in CSDN. There are 18 stuffing bits per packet, and 489 packets, which requires $\frac{489 \times 18}{9600} = 0.92$ sec. to transmit.

The end-to-end error rate is 10^{-4}. The probability of having no errors in a packet that is 1,122 bits long is:

$$(0.9999)^{1122} = 0.894$$

Therefore the probability of one or more errors in a packet is $1-0.894=0.106$. The expected number of packet errors in the original transmission of 489 packets is about 52 packets. However, with this high an error rate, the fact that retransmitted packets can also be in error must be considered. As with CSDN, the two-way delay is 94 msec to which must be added the time to send a 6-byte ACK at 9600 bits/sec which is 5 msec, for a total delay of 99 msec before the transmitter realizes that an error has occured. This is $\frac{99}{117} = 0.85$ of the time required to transmit a data packet at 9600 bits/sec. Since the error packet and the one following it also had to be transmitted, 2.85 packets must be retransmitted for each packet received in error. Therefore a minimum of $52 \times 2.85 = 148$ packets must be retransmitted. But these retransmitted packets can also have errors. Iterative calculations show that a total of 700 packets must be transmitted to get 489 error-free packets. Of

the 700 packets transmitted, 700x0.106=74 will be in error, which then requires 74x2.85=211 packets to be retransmitted. The 211 retransmitted packets plus the 489 original data packets equals the 700 total packets transmitted. The total time required for retransmitting packets is 211x0.117=24.69 seconds.

The link header is 6 bytes, which takes $\frac{6x8x489}{9600}$= 2.45 sec. to transmit. The link is set up by transmitting a supervisory message of 6 bytes, which takes 5 msec at each end, or 10 msec. To this is added the two-way delay of 94 msec, for a total of 104 msec. Therefore the link set-up takes 0.10 sec.

4.3.3.3 Network Overhead

As for the CSDN, the functions of the Network Protocol are not required for the PSTN, but it must be used for generality. Set-up requires a 25-byte two-way transmission, which requires 21 msec each way, or a 42 msec, plus the two-way delay of 94 msec, for a total of 136 msec, or 0.14 sec. In addition, the protocol is torn down by the return of the final ACK, which is 10 bytes and takes 8 msec to transmit in addition to the 94 msec round-trip, or a total of 102 msec, or 0.10 sec. The network header is only 2 bytes per packet which takes 0.82 sec. to transmit.

4.3.3.4 Transport Overhead

The Transport Level is setup by the two-way transmission of a 20-byte message, which takes 17 msec each way or 34 msec. Added to the two-way delay of 94 msec, gives 128 msec, or 0.13 sec.

As with CSDN, there will be about 122 Transport Blocks, requiring

368 header bytes. These will take about 0.35 sec to transmit. The final half block of 256 bytes will take 0.23 sec to transmit.

4.3.3.5 Session Overhead

The Session is started by a 96-byte message, which takes 80 msec to transmit each way, or 160 msec. Adding this to the two-way delay, 94 msec, gives a total time of 254 msec, or 0.25 sec to set up the Session Level protocol.

4.3.3.6 Presentation and Application Overhead

As with PSDN, it does not appear that there will be significant overhead from these protocol levels.

4.3.3.7 Summary of PSTN Baseline Throughput

Table 4-25 summarizes the calculations made for the PSTN throughput. The total transmission time is 82.26 seconds, which is only slightly more than the 80.10 seconds for PSDN, but is much larger than the 13.73 seconds for CSDN. The dominant factor in limiting the throughput is the requirement for retransmitting packets because of errors.

4.3.4 Sensitivity of Throughput to Baseline Assumptions

In order to determine the sensitivity of the results presented in Section 4.3.3 to the assumptions used in the baseline system, a selected set of baseline parameters were varied one at a time and the throughput calculated. The following sections discuss the variations used and the results obtained.

Table 4-25

Throughput Calculation Summary

Public Switched Telephone Network

Baseline	
Basic FAX Transmission	52.08
Link Overhead	
Header	2.45
Stuffing Bits	.92
Error Retrans.	24.69
Set-up	.10
Network Overhead	
Header	.82
Set-up	.14
Final ACK	.10
Transport Overhead	
Set-up	.13
Header	.35
Final Block	.23
Session Overhead	
Set-up	.25
Total Transmission Time	82.26
% Overhead	57.9

4.3.4.1 Number of Nodes

In varying the number of nodes, there are two main effects. The first is that the round-trip delay time varies, by 20 msec per node, which affects set-up and tear-down times. In addition, the number of nodes will probably affect the end-to-end BER. The end-to-end BER has been partitioned into local (user to node) links and network (node to node) links. The local link BER is assumed to be 10^{-5}, which is consistent with the assumption used for the PSDN. The network link BER is assumed to be 2×10^{-5}. For the 5-node baseline system there are two local links and four network links, which means that the end-to-end BER is 10×10^{-5}, or 10^{-4}, which is the value assumed for the PSTN baseline.

Table 4-26 summarizes the calculations for various number of nodes. Note the large effect of error retransmissions on throughput. This is because for a large number of nodes the end-to-end BER becomes large, and at the same time the longer round-trip delay means that for each error more packets must be retransmitted.

The throughput results are summarized in Figure 4-19, which shows very low throughput for a large number of nodes.

4.3.4.2 Number of Satellite Links

Table 4-27 summarizes the calculations for 0 or 1 satellite link, which increases the link propagation time from 10 to 250 msec. The use of two or more satellite links resulted in a situation that prevented any throughput, owing to the large number of packets that must be retransmitted for each error. As shown in Table 4-27, even one

Table 4-26

Throughput Calculation Summary

Public Switched Telephone Network

Number of Nodes	1	2	3	5	8	10
Basic FAX Transmission	52.08	52.08	52.08	52.08	52.08	52.08
Link Overhead						
Header	2.45	2.45	2.45	2.45	2.45	2.45
Stuffing Bits	.92	.92	.92	.92	.92	.92
Error Retrans.	2.81	6.55	11.11	24.69	70.32	166.14
Set-up	.02	.04	.06	.10	.16	.20
Network Overhead						
Header	.82	.82	.82	.82	.82	.82
Set-up	.06	.08	.10	.14	.20	.24
Final ACK	.02	.04	.06	.10	.16	.20
Transport Overhead						
Set-up	.05	.07	.09	.13	.19	.21
Header	.35	.35	.35	.35	.35	.35
Final Block	.23	.23	.23	.23	.23	.23
Session Overhead						
Set-up	.17	.19	.21	.25	.31	.35
Total Transmission Time	59.98	63.82	68.48	82.26	128.19	224.19
% Overhead	15.2	22.5	31.5	57.9	146.1	330.5

Figure 4-19

Number of Nodes vs. PSTN Throughput

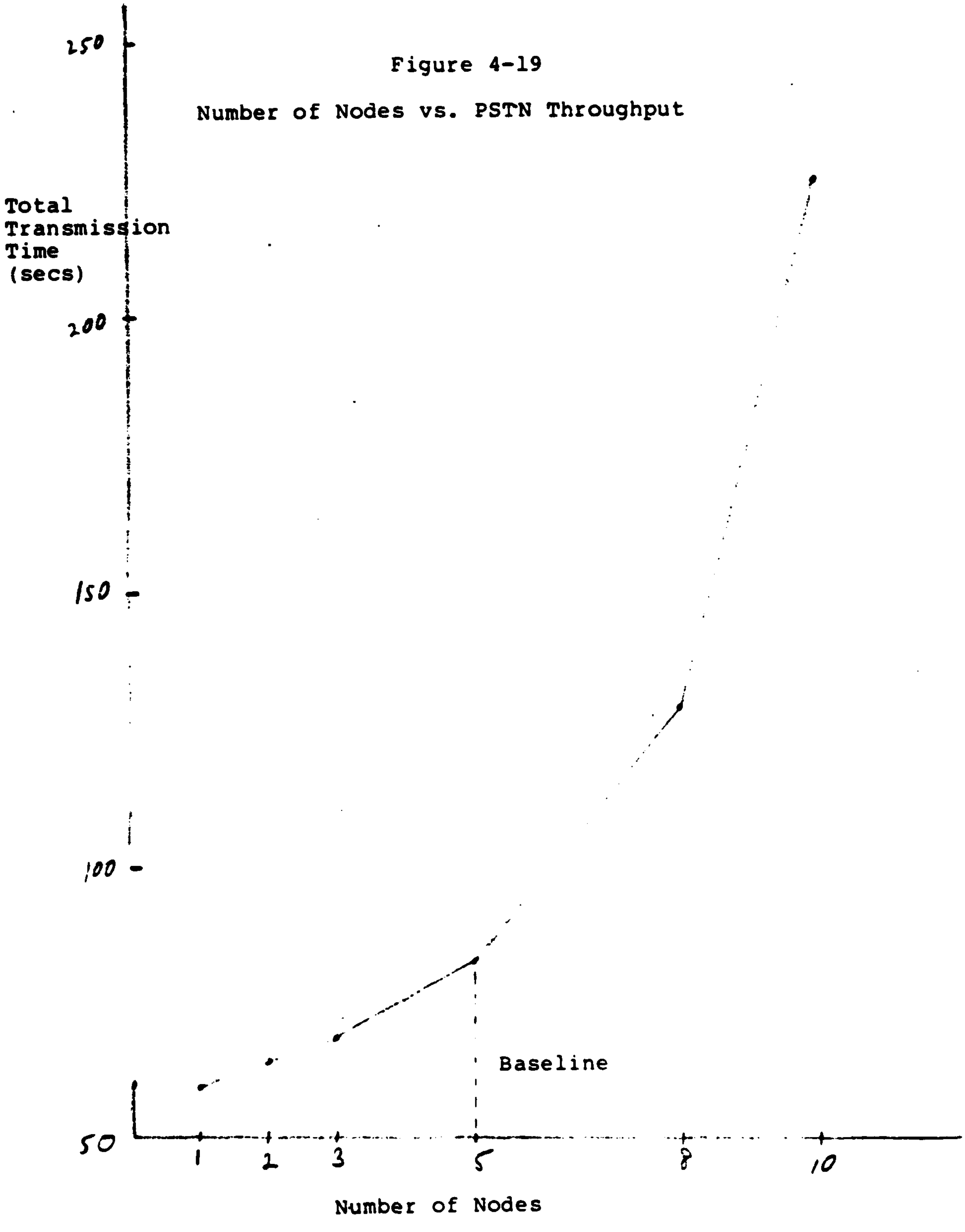


Table 4-27

Throughput Calculation Summary

Public Switched Telephone Network

No. of Satellite links	Ø	1
Basic FAX Transmission	52.Ø8	52.Ø8
Link Overhead		
Header	2.45	2.45
Stuffing Bits	.92	.92
Error Retrans.	24.69	159.94
Set-up	.1Ø	.58
Network Overhead		
Header	.82	.82
Set-up	.14	.62
Final ACK	.1Ø	.58
Transport Overhead		
Set-up	.13	.61
Header	.35	.35
Final Block	.23	.23
Session Overhead		
Set-up	.25	.73
Total Transmission Time	82.26	219.91
% Overhead	57.9	322.3

satellite link greatly increases the transmission time due to error retransmissions. The total throughput is shown in Figure 4-20.

4.3.4.3 Packet Size

Increasing the packet size from 128 bytes to 256 or 512 bytes gives the results shown in Table 4-28. The error retransmission dominates, and becomes worse as the packet size becomes larger, because more data must be retransmitted for each error. In the CSDN data rates were high, but here the retransmission takes a long time because of the slower data rate. In fact, throughput may be improved with a smaller data packet. The throughput results are shown in Figure 4-21.

4.3.4.4 Error Rate

The throughput was calculated for end-to-end error rates of 10^{-5}, 2×10^{-4}, and 3×10^{-4}, in addition to the baseline value of 10^{-4}. Error rates slightly above 3×10^{-4} resulted in no throughput. The calculations are shown in Table 4-29. Only the error retransmissions are affected, with very large times at 2×10^{-4} BER and above. Therefore throughput, as shown in Figure 4-22, is very sensitive to error rate.

4.3.4.5 Length of FAX Page

Table 4-30 summarizes the throughput calculations for various FAX message lengths. Notice that the percentage overhead is only slightly smaller for the longest page than the smallest page. Therefore it is concluded that the results are not sensitive to page length in bits. The throughput results are shown in Figure 4-23.

Figure 4-20

Number of Satellite Links vs. PSTN Throughput

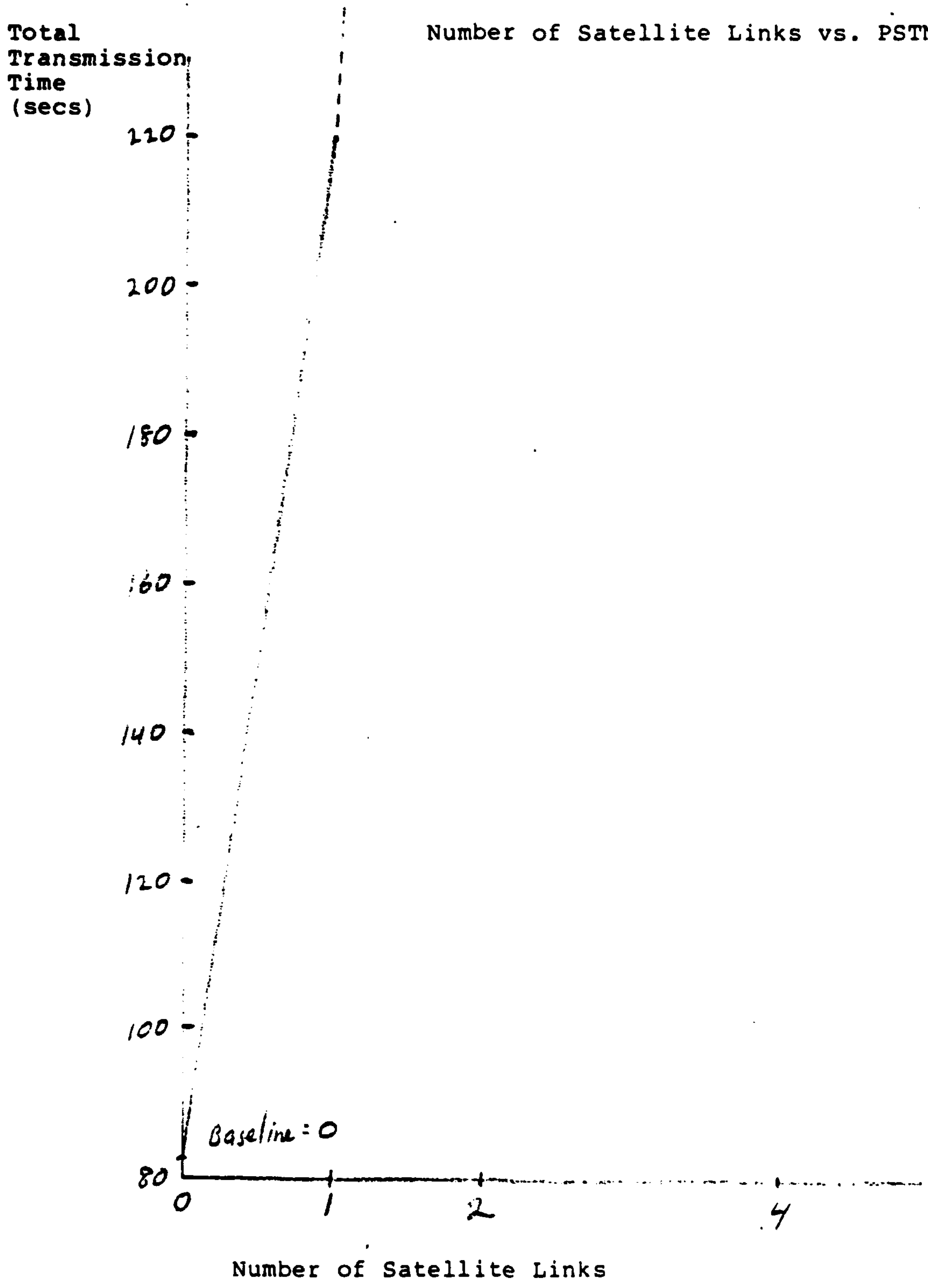


Table 4-28

Throughput Calculation Summary

Public Switched Telephone Network

Packet Size (bytes)	128	256	512
Basic FAX Transmission	52.08	52.08	52.08
Link Overhead			
Header	2.45	1.22	.61
Stuffing Bits	.92	.86	.85
Error Retrans.	24.69	49.50	178.13
Set-up	.10	.10	.10
Network Overhead			
Header	.82	.40	.20
Set-up	.14	.14	.14
Final ACK	.10	.10	.10
Transport Overhead			
Set-up	.13	.13	.13
Header	.35	.35	.35
Final Block	.23	.23	.23
Session Overhead			
Set-up	.25	.25	.25
Total Transmission Time	82.26	105.36	233.17
% Overhead	57.9	102.3	347.7

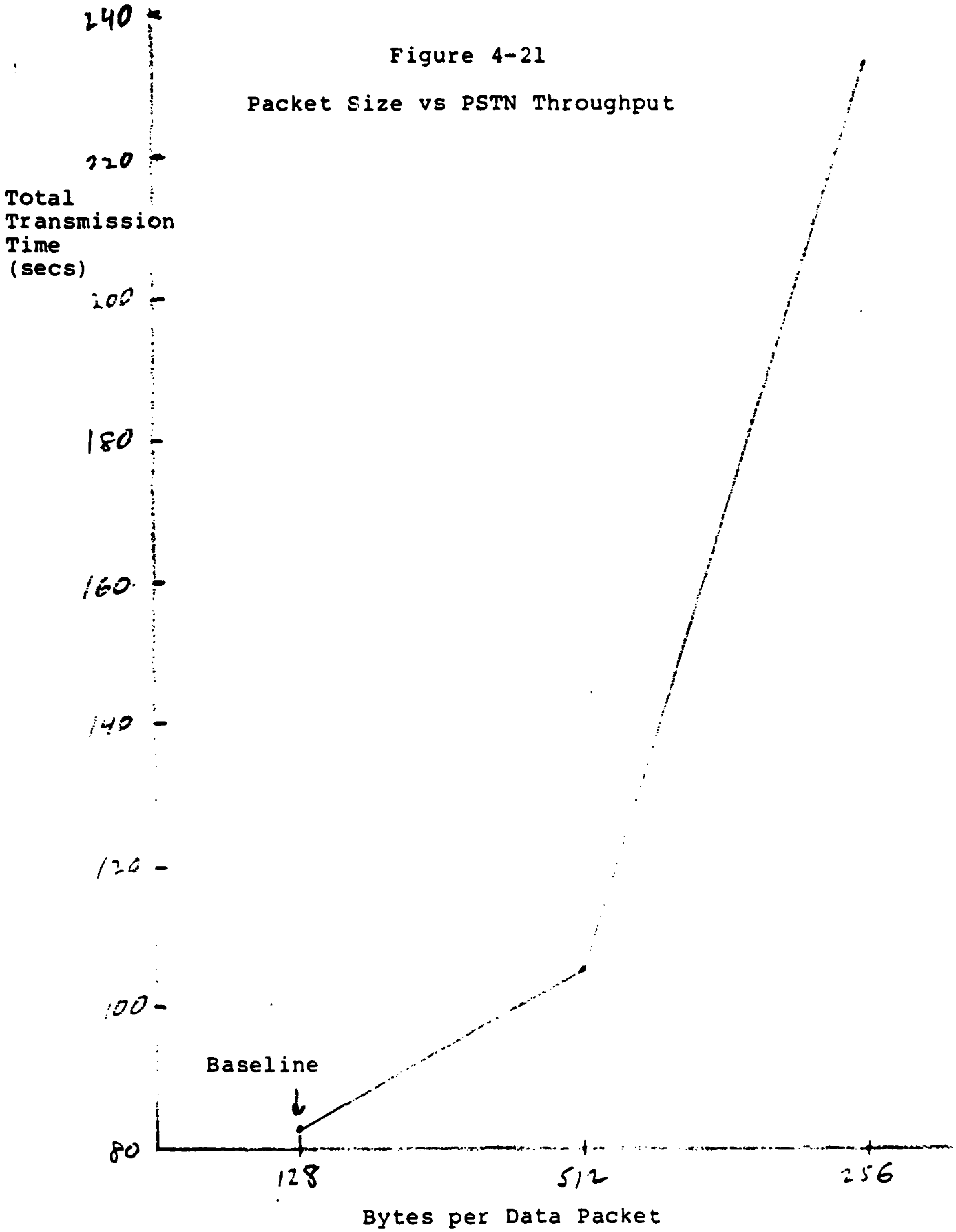


Figure 4-21

Packet Size vs PSTN Throughput

Table 4-29

Throughput Calculation Summary

Public Switched Telephone Network

End-to-End Error Rate	10^{-5}	10^{-4}	$2x10^{-4}$	$3x10^{-4}$
Basic FAX Transmission	52.08	52.08	52.08	52.08
Link Overhead				
Header	2.45	2.45	2.45	2.45
Stuffing Bits	.92	.92	.92	.92
Error Retrans.	1.87	24.69	77.10	252.72
Set-up	.10	.10	.10	.10
Network Overhead				
Header	.82	.82	.82	.82
Set-up	.14	.14	.14	.14
Final ACK	.10	.10	.10	.10
Transport Overhead				
Set-up	.13	.13	.13	.13
Header	.35	.35	.35	.35
Final Block	.23	.23	.23	.23
Session Overhead				
Set-up	.25	.25	.25	.25
Total Transmission Time	59.44	82.26	134.67	310.29
% Overhead	14.1	57.9	158.6	495.8

Figure 4-22

Error Rate vs. PSTN Throughput

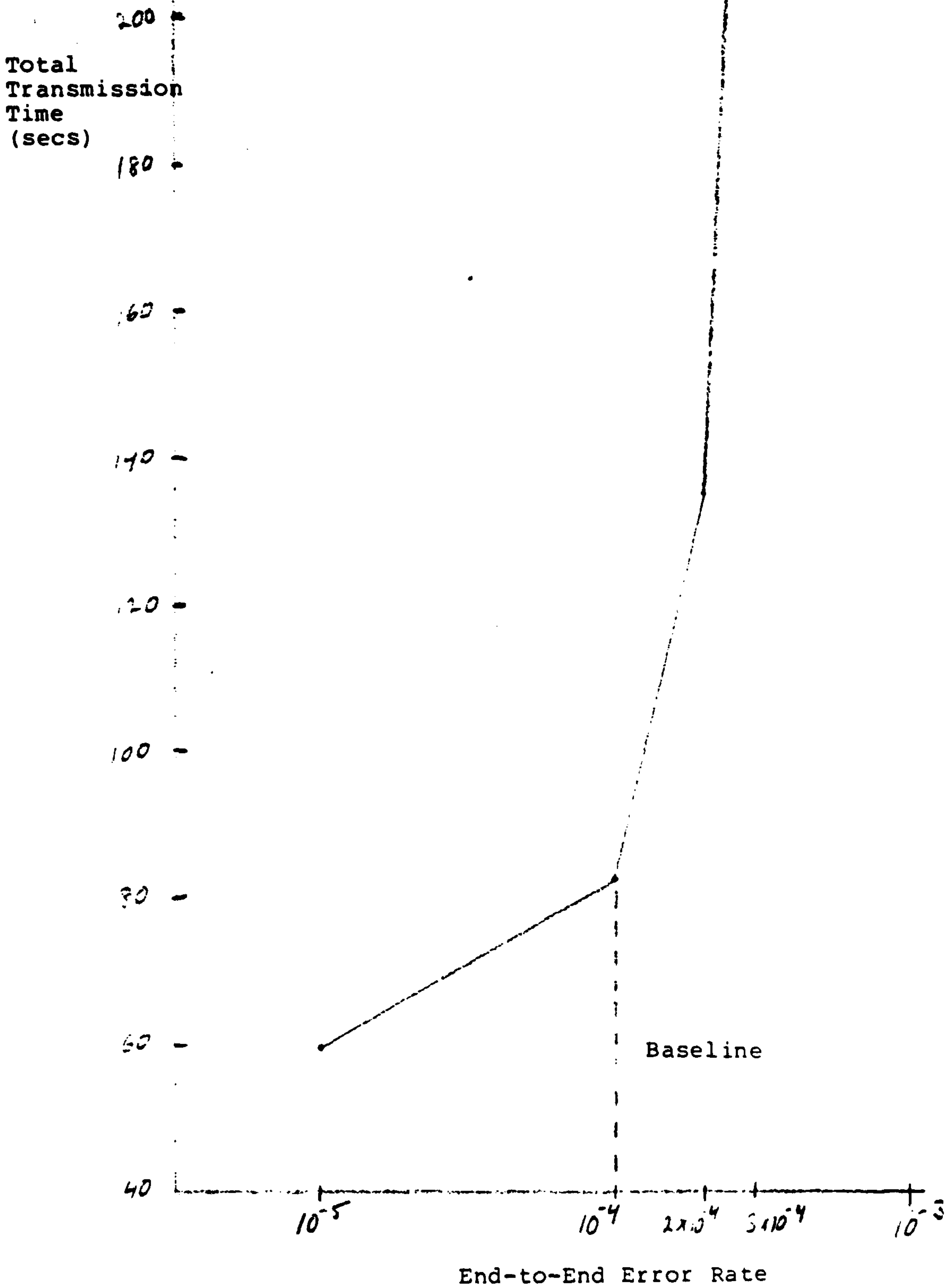


Table 4-30

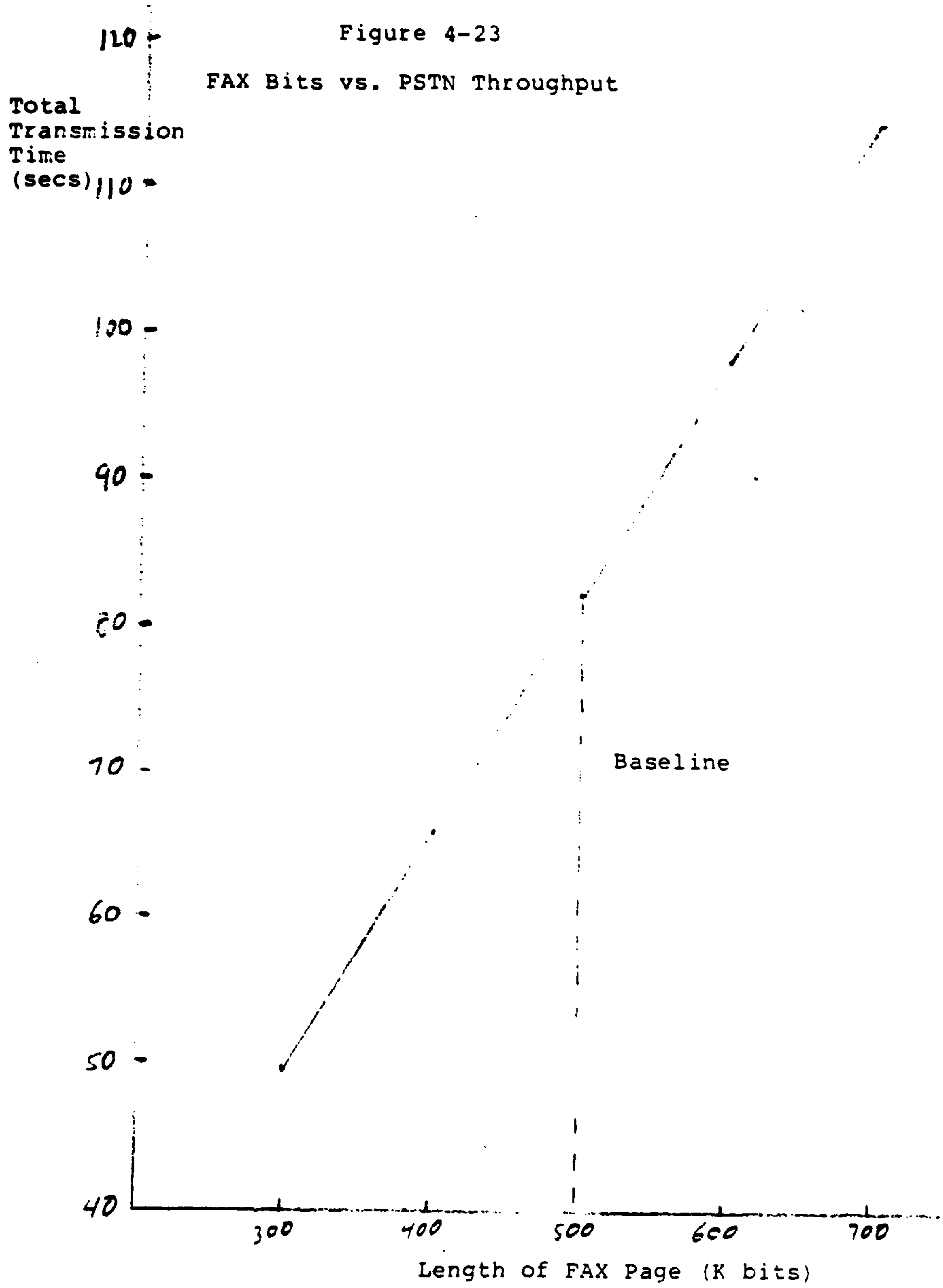
Throughput Calculation Summary

Public Switched Telephone Network

Length of FAX Page (Kbits)	300K	400K	500K	600K	700K
Basic FAX Transmission	31.25	41.67	52.08	62.50	72.92
Link Overhead					
Header	1.47	1.96	2.45	2.93	3.42
Stuffing Bits	.55	.73	.92	1.10	1.28
Error Retrans.	14.79	19.74	24.69	29.58	34.53
Set-up	.10	.10	.10	.10	.10
Network Overhead					
Header	.49	.65	.82	.98	1.14
Set-up	.14	.14	.14	.14	.14
Final ACK	.10	.10	.10	.10	.10
Transport Overhead					
Set-up	.13	.13	.13	.13	.13
Header	.23	.27	.35	.40	.47
Final Block	.23	.23	.23	.23	.23
Session Overhead					
Set-up	.25	.25	.25	.25	.25
Total Transmission Time	49.73	65.97	82.26	98.44	114.71
% Overhead	59.1	58.3	57.9	57.5	57.3

Figure 4-23

FAX Bits vs. PSTN Throughput



5.0 Summary and Conclusions

The throughput of Group 4 facsimile transmission has been analyzed for three types of communication networks: Packet Switching Data Network (PSDN), Circuit Switched Data Network (CSDN), and Public Switched Telephone Network (PSTN). Throughput was measured by the amount of time required to send a single facsimile page of 500,000 encoded bits.

The results are summarized in Table 5-1 for the baseline assumptions used for each network. The CSDN has a much higher throughput than the PSDN and the PSTN, primarily because it operates at a data rate of 56,000 bits per second, as opposed to 9600 bits per second for the other two. However, the overhead, as a percent of the basic facsimile transmission time, is in the range of 50 to 60% in each case.

For each network, there is a different factor that dominates the overhead. For PSDN, this factor is the halts that are forced in transmission as a result of the network window. This factor alone accounts for 63% of the total overhead. The window halts can be greatly reduced by reducing network loading by other customers, increasing the window, or by transmitting over only a few nodes. Increasing the window for all facsimile customers could lead to severe network congestion.

For CSDN, the conversion from voice to data mode is the dominating factor, using 70% of the total overhead. This time is required only once for a transmission, so a multi-page transmission would reduce the importance of this factor.

Table 5-1

THROUGHPUT CALCULATION SUMMARY

Network	PSDN	CSDN	PSTN
Basic FAX Transmission	52.08	8.93	52.08
Link Overhead			
Header	2.45	2.45	2.45
Stuffing Bits	.92	.16	.92
Source Error Retrans.	1.40	.07	24.69
Sink Error Retrans.	.50	.50	.50
Convert to Data Mode	-	3.30	-
Set-up	.02	.10	.10
Network Overhead			
Header	1.63	.14	.82
Window	17.60	-	-
Link Error Retrans.	-	-	-
Set-up	.63	.10	.14
Final ACK	.73	.10	.10
Transport Overhead			
Set-up	.61	.10	.13
Header	.35	.05	.35
Final block	.23	.04	.23
Session Overhead			
Set-up	.95	.12	.25
Total Transmission Time	80.10	13.63	82.26
% Overhead	52.8	52.6	57.9

For PSTN, packet retransmission due to transmission errors is the dominating factor, using 82% of the total overhead. This overhead can be reduced by lowering the error rate, or by using fewer nodes, which reduces the end-to-end BER and at the same time reduces the number of packets that must be retransmitted for each error.

The baseline systems used no satellite links. When some of the network links are converted to satellite links the throughput decreases drastically, particularly the PSTN, which cannot support more than one satellite link.

Increasing the number of bytes in a data packet from the baseline value of 128 to 256 and 512 has little effect for PSDN, improves throughput for CSDN, and decreases throughput for PSTN. The difference between CSDN and PSTN is due to the differences in data rates and error rates.

APPENDIX A

CCITT DRAFT RECOMMENDATION T.a

APPARATUS FOR USE IN THE GROUP 4 FACSIMILE SERVICE

CCITT

STUDY GROUP VIII
WORKING PARTIES VIII/2, 3 AND 4

Temporary Document No. 103

Geneva, 24 May - 3 June 1983

Question : 7/VIII

SOURCE : SPECIAL RAPPORTEURN GROUP 4 FACSIMILE APPARATUS

TITLE : DRAFT RECOMMENDATION T.a

APPARATUS FOR USE IN THE GROUP 4 FACSIMILE SERVICE

CONTENTS

The CCITT,

considering

(a) that Recommendation T.2 refers to Group 1 type apparatus for ISO A4 document transmission over a telephone-type circuit in approximately six minutes;

(b) that Recommendation T.3 refers to Group 2 type apparatus for ISO A4 document transmission over a telephone-type circuit in approximately three minutes;

(c) that Recommendation T.4 refers to Group 3 type apparatus for ISO A4 document transmission over a telephone-type circuit in approximately one minute;

(d) that there is a demand for Group 4 apparatus which incorporates means for reducing the transmission time and assures essentially error-free reception of the documents;

(e) that Telematic terminals including Group 4 facsimile apparatus are to be standardized, taking into account for the commonality among these terminals;

(f) that there is a demand for mixed-mode of operation where both facsimile- coded information and character-coded information can be treated within a page by the same apparatus;

(unanimously) declares the view

that Group 4 facsimile apparatus as defined in Recommendation T.0 should be designed and operated according to the following standard.

1. General

1.1 Group 4 facsimile apparatus is used mainly on public data networks (PDN) including circuit-switched, packet switched, and the integrated services digital network (ISDN). The apparatus may be also used on the public switched telephone network (PSTN) where an appropriate modulation process will be utilized.

1.2 Group 4 facsimile apparatus can transmit and reproduce image coded information essentially without transmission errors.

1.3 Group 4 facsimile apparatus has the means for reducing the redundant information in facsimile signals.

1.4 The basic image type of the Group 4 facsimile apparatus is black and white.

Other image types, e.g. grey scale image or colour image are for further study.

1.5 There are three classes of Group 4 facsimile terminals:

~~a) Group 4 facsimile terminals definitions (see Recommendation T.a) is as follows~~

- Class 1. - Minimum requirement is a terminal able to send and receive documents containing facsimile encoded information (in accordance with Recommendation T.b[1] and S.a)[2].

- Class 2. - Minimum requirement is a terminal able to transmit documents which are facsimile encoded (in accordance with Recommendations T.b and S.a). In addition, the terminal must be capable of receiving documents which are facsimile coded (in accordance with Recommendations T.b and S.a), Teletex coded (in accordance with the basic coded character repertoire as defined in Recommendation S.61)[3] and also mixed-mode documents (in accordance with Recommendation S.a - when defined).

- Class 3. - Minim~~um terminal~~ requirement is a terminal which is capable of generating, transmitting and receiving facsimile coded documents (in accordance with Recommendations T.b and S.a), Teletex coded documents (in accordance with the basic coded character as

defined in Recommendation S.61) and mixed mode documents (in accordance with Recommendation S.a - when defined). Note 1

2. Scope of Recommendations concerning Group 4 facsimile apparatus

~~2.1~~

2.1 This Recommendation defines the requirements for Group 4 facsimile apparatus.

~~1.2~~

2.2 The rules to be followed in the Group 4 facsimile service are defined in Recommendation(s) F.......

~~1.3~~

2.3 The Group 4 facsimile coding scheme and facsimile control functions are defined in Recommendation T.b. .

~~2.4~~

2.4 All Group 4 facsimile apparatus ~~has to~~ communicates with unique procedures that are described as follows:

a. the interface to the physical network is defined in this Recommendation; Note 2

b. the transport end-to-end control procedure is defined in Recommendation S.70 [4];

c. Group 4 facsimile control procedures are defined in Recommendations S.62[5] and S.a Note 3

Note 1 ~~Note:~~ the above definitions are extracted from Study Group I where "terminal" is used instead of "apparatus".

Note 2 ~~Note~~: Recommendation S.71 [6] may be applicable for PSTN operation.

Note 3: Recommendations S.62 and S.70 are used in Group 4 facsimile, Teletex and mixed-mode terminals.

2.5

The framework of recommendations for Group 4 facsimile apparatus mentioned above is shown in Annex A.

3. General characteristics of the apparatus

3.1 Basic characteristics

3.1.1 The Group 4 facsimile apparatus provides the means for direct document transmission from any subscriber to any other subscriber.

3.1.2 All apparatus participating in the international Group 4 facsimile service has to be compatible with another at the basic level defined in this Recommendation. Additional operational functions may be invoked.

3.1.3 The range of data rates are described in Section 6. Detailed arrangements on a national level are left to the Administrations concerned, as it is recognized that national implementation of the Group 4 facsimile service on various types of network may involve national operation at different data throughout rates.

3.1.4 The page is the basis for facsimile message formatting and transmission. Both A4 and North American paper formats are taken into account.

3.1.5 Facsimile coding schemes are applied in order to reduce the redundant information in facsimile signals.

3.1.6 The apparatus must have the ability to reproduce facsimile messages. The content, layout and format of facsimile messages must be identical at the transmitting and receiving apparatus.

3.1.7 The reproducible area is defined within which facsimile messages are assured to be reproduced. (See 3.2.6)

3.1.8 The Group 4 Class 2 and 3 facsimile apparatus must provide means for fully automatic operation. Class 1 is for further study.

3.1.9 All classes of Group 4 facsimile apparatus shall incorporate the functions defined as basic for the Group 4 facsimile service in Section 3.2 below. In addition, optional functions can be incorporated. In this Recommendation, the optional functions are divided into CCITT standardized options and nationally and/or privately

specified options.

3.2 Basic functions

3.2.1 Group 4 facsimile apparatus shall be capable of handling:

a. the basic end-to-end control procedures as defined in Recommendation S.62;

b. the presentation control procedures as defined in Recommendation S.a

c. the basic facsimile coding scheme defined in Recommendation T.b;

d. the control functions associated ~~to~~ with the basic facsimile coding scheme defined in Recommendation T.b;

3.2.2 All classes of Group 4 apparatus shall have the following provisions for facsimile messages:

a. provision for scanning the documents to be transmitted (see paragraph 3.2.5)

b. provision for receiving and presenting hard or soft copies of the documents

3.2.2.1 In addition Group 4 Class 2 apparatus shall have provision for receiving and displaying basic Teletex and mixed-mode documents.

3.2.2.2 In addition to the requirements for Group 4 Class 2 apparatus, Class 3 apparatus shall have provisions for generating and transmitting basic Teletex and mixed-mode documents.

3.2.3 Basic page formatting functions are as follows:

a. vertical page orientation;

b. page size of [redacted] ISO A4 [redacted];

c. reproducible area/printable area - to be defined taking into account A4 and North American paper formats and ISO 3535;

3.2.4 Terminal Identification

Each Group 4 facsimile apparatus is equipped with a unique identification. Details of the identification are given to Recommendation F. ......

3.2.5 Scanning

The message area should be scanned in the same direction in the transmitter and receiver. Viewing the message area in a vertical plane, the picture elements shall be processed as if the scanning direction were from left to right with subsequent scans adjacent to and below the previous scan.

3.2.6 Page sizes and reproducible area

3.2.6.1 Sometimes paper length may not be specified, because the paper end is detected by paper scanning.

3.2.6.2 Reproducible area satisfies the requirement defined in Recommendation F .

3.2.7 Group 4 facsimile transmission pel density ~~resolution~~ requirements

The Group 4 facsimile resolution ~~[illegible]~~ require-ments and ~~[illegible]~~ their tolerances are given below

Resolution ~~Resolution~~ ~~transmission~~ ~~pel density~~	Horizontal & Vertical Tolerance	Status
200 x 200 ppi	± 1%	standard ~~[illegible]~~ cl.1, cl.2, cl.3
240 x 240 ppi	± 1%	optional cl.1, cl.2, cl.3
300 x 300 ppi	± 1%	standard cl.2, cl.3
400 x 400 ppi	± 1%	optional cl.1, cl.2, cl.3

* Center line referencing will be used for paper positioning. Each page will be positioned on the scanner so that the center line is in registration with the (number of pels/line)/2 ~~[illegible]~~

** Set to white ~~zero~~ an equal number of pels on the left and right side of the page to fit the paper format

Specific values for the number of pels per line, ~~[illegible]~~ scan line length and number of scan lines per pages are given in table 1/T.a for all the Group 4 resolutions for A4, North American, B4, and A3 ~~paper~~. Table 2/T.a and Figure 1/T.a specify the blanking procedure for A4 and North American paper. The same procedure is used for the other paper formats. ~~The~~

The raster point in the upper left corner of an ~~A4~~ ISO page is used as a referance for portrait mode character printing. This raster point, termed the (1,1) Raster Reference Point, is used as a starting point for determining character margins and positions. This is also illustrated in figure 1/T.a.

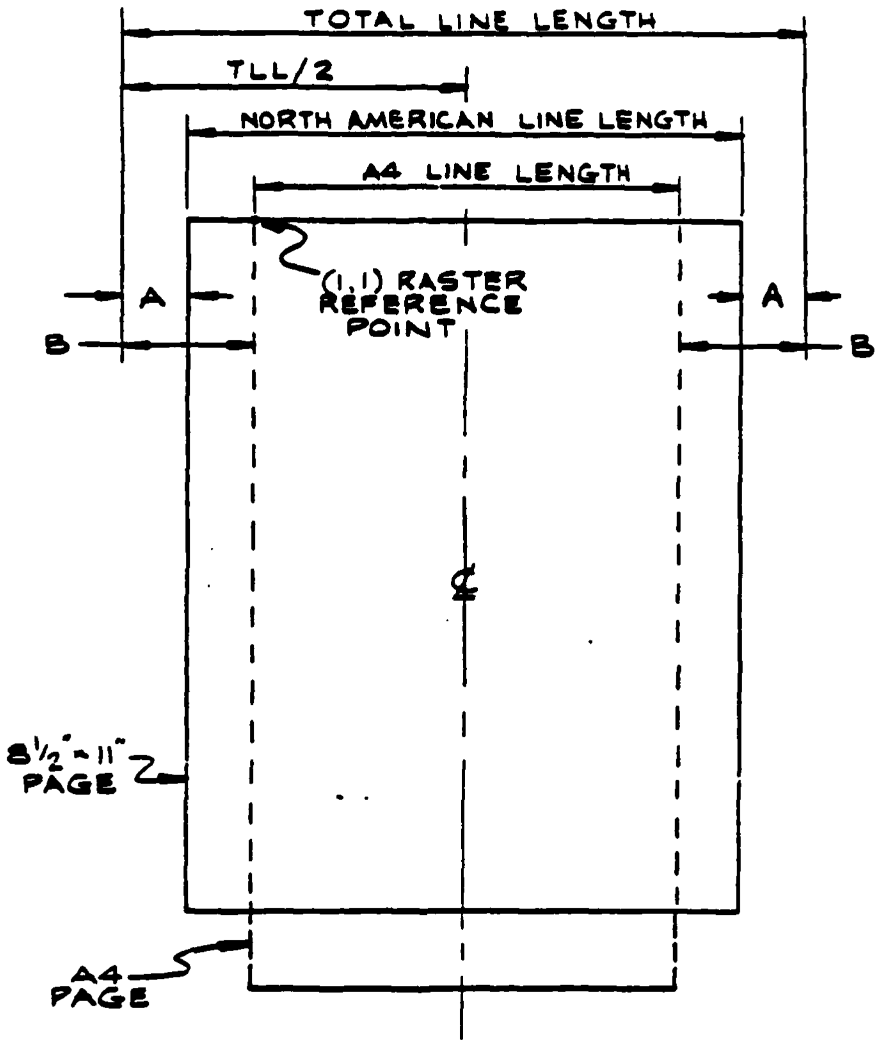
TABLE 1/T.a – The number of pels and the scan line length for different page sizes.

		ISO A4	North American	ISO B4	ISO A3
Number of picture element along a scan line	Resolution (pels/25.4mm)				
	200	1728	1728	2048	2432
	240	2074	2074	2458	2918
	300	2592	2592	3072	3648
	400	3456	3456	4096	4864
Scan line length(mm) [A]		219.46	219.46	260.10	308.86
Paper width (mm) [B]		210	215.9	250	297
[A] – [B]		9.46	3.56	10.10	11.86
Number of scan lines per page for each pel-transmission density	200	2339	2200	2780	3307
	240	2806	2640	3335	3968
	300	3508	3300	4169	4961
	400	4677	4400	5559	6614

Table 2/T.a. Blanking and Address Reference Point for A4 and North American Paper

Resolution (ppi)	Pels Per Line	8 1/2x11 Line (pels)	A4 Line (pels)	Blanked Margins A (pels)	Blanked Margins B (pels)	Address (1,1) Ref Point	Total Line Length (mm)
200x200	1728	1700	1654	14	37	(38,1)	219.46
240x240	2074	2040	1984	17	45	(46,1)	219.46
300x300	2592	2550	2480	21	56	(57,1)	219.46
400x400	3456	3400	3308	28	74	(75,1)	219.46

FIG. 1/T.a


TOTAL LINE LENGTH
TLL/2
NORTH AMERICAN LINE LENGTH
A4 LINE LENGTH
(1,1) RASTER REFERENCE POINT
A
A
B
B
8½" x 11" PAGE
A4 PAGE

3.2.8 Group 4 facsimile class structure

Table 3/T.a shows the class structure of Group 4 facsimile apparatus.

Table 3/Ta. Class structure

Class	1	2	3
Standard pel transmission density	200 note 2	200 and 300 note 2	200 and 300 note 2
optional pel transmission density	240 and/or 300 and/or 400	240 and/or 400 note 1	240 and/or 400 note 1
pel conversion capability in standard	not req'd	yes	yes
Basic Teletex	not req'd	reception only	yes
Teletex Mixed Mode	not req'd	reception only	yes
Page Memory	not req'd	yes	yes

Notes

note 1: To achieve a high service quality, the pel density of the scanner and printer should be greater than or equal to the transmission pel density. This requirement is waived for a terminal which has a scanner or printer with a pel density of 240×240 ppi and can transmit at 300 ppi. In this case, the 240×240 ppi terminal will exceptionally meet the standard class 2/3 requirement.

Note 2 Administrations may determine which class with options is to be used for their national service. Standardization work has to continue with the goal of achieving a uniform standard.

Note 3 For a period of four years, Group 4 Class 1 apparatus may be manufactured utilizing Group 3 scanner/printer components.

Note 4: When resolution conversion is necessary, the conversion is done on the side which minimizes the transmission cost and time. An exception would be a 240 x 240 ppi terminal transmitting to a 300 x 300 ppi terminal which is operating at the standard transmission density.

3.2.8 Facsimile coding schemes

3.2.8.1 In order to reduce the redundant information in facsimile signals, the basic facsimile coding scheme is defined in Recommendation T.b. is used This coding scheme is used assuming that transmission errors are corrected by control procedures in lower levels.

3.2.8.2 On an optional basis an apparatus can use other CCITT standardized coding schemes defined in Recommendation T.b.

3.3 CCITT-standardized optional functions

3.3.1 The possibility of using optional functions can be negotiated ~~between apparatus~~ during a handshaking procedure in the end-to-end control procedure (See Recommendation S.62).

3.3.2 The optional functions are invoked by presentation control procedures (See Recommendation S.a).

3.3.3 As the service develops, additions and changes to the CCITT-standardized optional functions listed below may be needed.

a. optional coding schemes defined in Recommendation T.b;

b. control functions associated with optional coding schemes;

c. grey scale images;

d. colour images;

e. resolution conversion algorithms;

3.3.4 Optional page formatting functions are as follows:

a. page sizes of ISO B4 and ISO A3;

b. other page formats are for further study.

3.4 Optional functions for national standardization or private use

The CCITT standardization includes the necessary rules and means for indication of, or escape into, functions specified nationally or for private use (see Recommendations S.62 and S.a).

3.5 Default conditions

In the absence of specific indication, the receiving apparatus shall assume the following conditions;

a. communication (as specified in Recommendation S.62):

- one way (calling apparatus transmitting the facsimile message);
- normal document;

b. coding scheme;

- basic facsimile coding scheme

c. image type:

- black and white two-level image

d. presentation

- page size of ISO A4
- resolution of 200 pels per 25.4 mm in both horizontal and vertical directions
- number of picture elements along scan line of 1728 pels per 219.46 mm
- vertical page orientation

4. Message handling in mixed-mode of operation

4.1

In mixed-mode of operation facsimile-coded information and character-code information can be treated within a page.

4.2 Facsimile information is coded and treated by facsimile coding schemes and control functions as defined in Recommendation T.b.

4.3 Character information is coded and treated by character repertoire and control functions as defined in Recommendation S.61.

4.4 Mixed-mode of operation requires document structure and its presentation control procedures are defined in Recommendation S.a.

5. Communications

5.1 Terminal identification

Each Group 4 facsimile apparatus is equipped with a unique identification. Details of the identification are given in Recommendation F..

5.2 Storage

The minimum storage requirements for Group 4 Class 2 and Class 3 apparatus ~~are~~ remain to be defined.

5.3 Call Identification

The control procedures include the exchange of reference information prior to sending any document. Details of the Call Identification Line are covered in Recommendation F.200[7] Printing the call identification line at the top of each page is an option.

6. Network-related requirements

6.1 Networks

The Group 4 facsimile transport service can be provided ~~by~~ using a circuit-switched data network (CSDN), a packet-switched data network (PSDN), a public switched telephone network (PSTN), or an integrated services digital network (ISDN). In all types of network the Group 4 facsimile apparatus will

provide automatic answering, transmission, reception and clearing.

6.2 Circuit-switched data network

a. functional and procedural aspect of the interface: Recommendation X.21 [8]

b. with external DCE - mechanical and electrical characteristics of the interface: Recommendation X.21

c. bit rates: user classes of service 4 to 7 in Recommendation X.1; [9] ~~[illegible]~~

d. link procedure: LAPB / X.75 [10]

6.3 Packet-switched data network

a. functional and procedural aspects of the interface: Recommendation X.25, levels 1, 2, 3; [11]

b. duplex transmission;

c. bit rates; user classes of service 8 to 11 in Recommendation X.1;

d. number of logical channels at a time: one or more, ~~than one~~

6.4 Public switched telephone network

a. physical and electrical aspects of the interface: Recommendation V. ; for further study ;

b. functional and procedural aspects of the interface: for further study;

c. link procedure: Recommendation S.71 may be applicable

d. bit rate: for further study

e. automatic answering: Recommendation V.25 [12]

6.5 Integrated services digital network (ISDN)

The operation of Group 4 facsimile apparatus on the ISDN can be achieved by the implementation of the relevant I Series Recommendations.

7. Indicators

7.1

Indicators should inform users about situations in which negative effects on the grade of service can be expected.

7.2

The following indicators are required:

a. apparatus unable to transmit (e.g. paper jam at transmitting end);

b. apparatus unable or soon unable to receive (e.g. paper jam or receiving memory nearly full)

c. operator assistance required;

d. message received in store.

8. Access to facsimile MHF

Users of Group 4 facsimile apparatus may wish to have access to the services offered by Message Handling Facilities, this requires the ability to generate Control Documents (See Recommendation S.62). The details are left for further study.

References

1 CCITT Draft Recommendation T.b Facsimile coding scheme for the Group 4 facsimile service.

2 CCITT Recommendation S.a Presentation control procedures for the telematic services, under study.

3 CCITT Recommendation Character repertoire and coded character sets for the international Teletex Service, Vol. VII, Fascicle VII. 2, Rec. S.61.

4 CCITT Recommendation Network - independent basic transport service for Teletex, Vol. VII, Fascicle VII. 2, Rec. S.70.

5 CCITT Recommendation Control procedures for Teletex and Group 4 facsimile services, Vol. VII, Fascicle VII. 2, Rec. S.62.

6 CCITT Recommendation LAPB extended for half-duplex physical level facility, Rec S.71 (provisionally approved)

7 CCITT Recommendation Telex Service, Vol II, Fasc. II.4, Rec. F.200

8 CCITT Recommendation Interface between terminal equipment (DTE) and data circuit terminating equipment (DCE) for synchronous operation on public data networks, Vol VIII, Fasc. VIII.3 Rec. X.21

9 CCITT Recommendation International user classes of service in public data networks, Vol VIII, Fasc. VIII.2, Rec. X.1

10 CCITT Recommendation Terminal and Transit call procedures and data transfer system on international circuits between packet switched data networks, Vol VIII, Fasc. VIII.3, Rec X.75

11 CCITT Recommendation Interface between data ~~circuit~~ terminal equipment (DTE) and data circuit terminating equipment (DCE) for terminals operating in the packet mode on public data networks, Vol VIII, Fasc VIII.2, Rec X.25.

12 CCITT Recommendation Automatic calling and/or answering equipment on the general switched telephone network, including disabling of echo suppressors on manually established calls, Vol. VIII, Fasc. VIII.1, Rec. V.25

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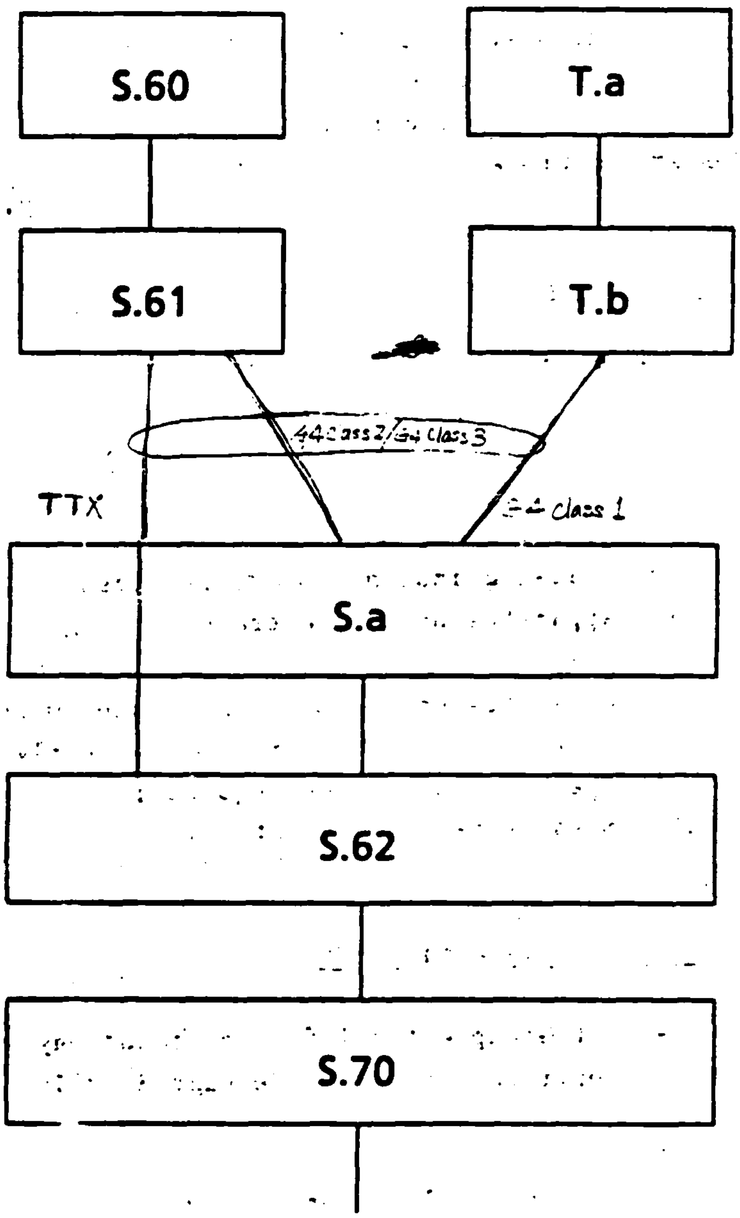
ANNEX A

(to Recommendation T.a)

Framework of Recommendations for Group 4 facsimile apparatus



APPENDIX B

CCITT DRAFT RECOMMENDATION T.b

FACSIMILE CODING SCHEMES AND CODING CONTROL FUNCTIONS FOR GROUP 4 FACSIMILE APPARATUS

SJC 5/24/83

CCITT

Temporary Document No. 28

STUDY GROUP VIII
WORKING PARTIES VIII/2, 3 AND 4

Geneva, 24 May - 3 June 1983

Question : 7/VIII

SOURCE: SPECIAL RAPPORTEUR ON GROUP 4 FACSIMILE APPARATUS

TITLE: DRAFT RECOMMENDATION T.b (2ND ISSUE)

1. Introduction

The Special Rapporteur's meeting on Group 4 facsimile apparatus was held at the KDD building, Tokyo, during March 9 - 15, 1983. At the meeting, the framework of Recommendations relevant to Group 4 facsimile were refined as follows,

Rec. T.a	:	Apparatus for use in the Group 4 facsimile service
Rec. T.b	:	Facsimile coding schemes and coding control functions for Group 4 facsimile apparatus
Rec. S.a	:	Presentation control procedure for the Telematic services

Rec. T.a newly drafted at the meeting is attached as Annex 1 to the Report of the Special Rapporteur's meeting on Group 4 facsimile apparatus, Tokyo, 8 - 15 March 1983. And the requirements for presentation control procedure of G4 facsimile apparatus and information filed length indicator were summarized as shown in the Temporary Document TD- of this meeting, May 24 - June 3 , 1983.

This document shows the Draft Rec. T.b amended at the Special Rapporteur's meeting.

2. Draft Rec. T.b

Rec. T.b was decided to describe the facsimile coding schemes and the relevant control functions. The contents of Rec. T.b are as follows,

1. General

   1.1 Scope
   1.2 Fundamental principles
   1.3 Definitions

2. Facsimile coding schemes and coding control functions for black and white images

   2.1 General
   2.2 Basic facsimile coding scheme
   2.3 Optional facsimile coding schemes for black and white images
   2.4 Facsimile coding control functions

3. Optional grey scale facsimile coding schemes and their coding control functions

4. Optional colour facsimile coding schemes and their coding control functions.

The amended draft Rec. T.b is attached as Annex 1 to this document.

3. Description of basic coding scheme in Rec. T.b.

The basic coding scheme of Group 4 facsimile apparatus is in principle same as the two-dimentional coding scheme of Group 3 facsimile apparatus which is specified in Rec. T.4. Therefore it was suggested at the meeting to seek advice from the CCITT secretariat on the description of the coding scheme,

* Complete description of coding scheme in Rec. T.b,
* Reference to Rec. T.4 in Rec. T.b

In order to assist CCITT secretariat to decide which description is suitable, the table of the difference between Group 3 two-dimensional coding scheme and Group 4 basic coding scheme was prepared. This table is attached to this document as Annex 2.

ANNEX 1

DRAFT RECOMMENDATION T.b (2nd issue)

FACSIMILE CODING SCHEMES AND CODING CONTROL FUNCTIONS FOR GROUP 4 FACSIMILE APPARATUS

1. General

1.1 Scope

1.1.1 This Recommendation T.b defines the facsimile coding schemes, and thier control functions to be used in the Group 4 facsimile.

1.1.2 This Recommendation should be read conjunction with the following Recommendations:

- T.a - Terminal equipment for use in the Group 4 facsimile service;
- S.a - Presentation control procedures for the Telematic services
- S.62 - Control procedures for Teletex and Group 4 facsimile services;
- S.70 - Network-independent basic transport service for Teletex;
- F... - Recommendations relevant to Group 4 facsimile

In addition, in the case of Group 4 class 2/3 (Teletex or mixed mode of operation), the following Recommendations should be also read:

- S.60 - Terminal equipment for use in the Teletex service
- S.61 - Character repertoire and coded character sets for the international Teletex service

1.2 Fundamental principles

1.2.1 Facsimile coding schemes and coding control functions

(1) Facsimile coding schemes consist of the basic facsimile coding scheme and optional facsimile coding schemes. They are defined in Section 2 and Sections 3 and 4, repectively.

(2) Facsimile coding schemes are specified assuming that transmission errors are corrected by control procedure on lower level.

(3) Basic facsimile coding scheme is the two-dimensional coding scheme which is in principle same as the two-dimensional coding scheme of Group 3 facsimile specified in Recommendation T.4.

(4) Optional facsimile coding schemes are not only specified for black and white images but also for grey scale images and colour images.

(5) Facsimile coding control functions are used in facsimile user information in order to change facsimile parameters or to invoke the end of facsimile block. They are definded in Section 2.4...

2. Facsimile coding schemes and coding control functions for black and white images

2.1 General

2.1.1 This Section specifies the facsimile coding schemes, and associated control functions for black and white images.

2.1.2 Facsimile coding schemes consist of the basic facsimile coding scheme and optional coding schemes.

2.1.3 The use of the optional facsimile coding schemes is subject to mutual agreement between terminals and shall be initiated by the appropriate procedural steps.

2.2 Basic facsimile coding scheme

2.2.1 Principle of coding scheme

This is a two-dimmensional line-by-line coding method in which the position of each changing picture element on the current or coding line is coding with respect position of a corresponding reference element situated on either the coding line or the reference line which immediately above the coding line. After the coding line has been coded, it becomes the reference line for the next coding line. The reference line for the first coding line in a page is an imaginary white line.

2.2.2 Definition of changing picture elements (see Figure 1/T.b)

A changing element is defined as an element whose "colour" (i.e. black or white) is different from that of the previous element along the same scan line.

- a_0: The reference or starting changing element on the coding line. At the start of the line a_0 is set on an imaginary white changing element situated just before the first element on the line. During the coding of the coding line, the position of a_0 is defined by previous coding mode. (See 2.2.3)
- a_1: The next changing element to the right of a_0 on the coding line.
- a_2: The next changing element to the right of a_1 on the coding line.
- b_1: The first changing element on the reference line to the right of a_0 and of opposite colour to a_0.
- b_2: The next changing element to the right of b_1 on the reference line.

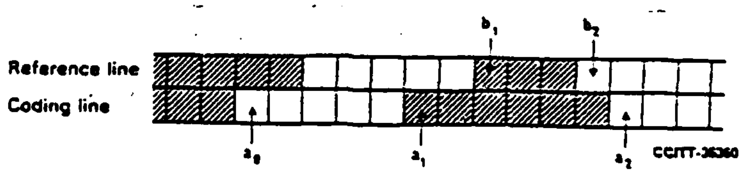


FIGURE 1/T.b - Changing picture element

2.2.3 Coding modes

One of the three coding modes are chosen according to the coding procedure described in Section 2.2.4 to code the position of each changing element along the coding line. Examples of the three coding modes ara given in Figure 2/T.b, 3/T.b and 4/T.b.

a) Pass mode (see Figure 2/T.b)
This mode is identified when the position of b_2 lies to the left of a_1.

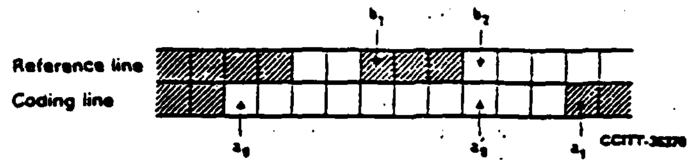


FIGURE 2/Tb - Pass mode

However, the state where b_2 occurs just above a_1, as shown in Figure 3/T.b is not considered as a pass mode.

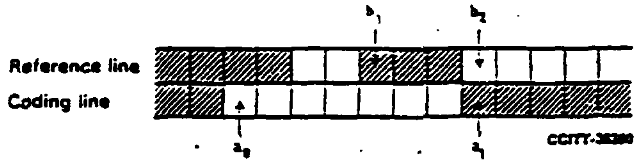


FIGURE 3/T.b - An example not corresponding to a Pass mode

b) Vertical mode
When this mode is identified, the position of a_1 is coded relative to the position of b_1. The relative distance a_1b_1 can take on one of seven values $V(0)$, $V_R(1)$, $V_R(2)$, $V_R(3)$, $V_L(1)$, $V_L(2)$ and $V_L(3)$, each of which is represented by a separate code word. The subscripts R and L indicate that a_1 is to the right or left respectively of b_1 , and the number in brackets indicates the value of the distance a_1b_1 . (See Figure 4/T.b)

c) Horizontal mode
When this mode is identified, both the run-lengths a_0a_1 and a_1a_2 are coded using the code words $H + M(a_0a_1)+M(a_1a_2)$. H is the flag code word 001 taken from the two-dimensional code table (Table 2/T.b). $M(a_0a_1)$ and $M(a_1a_2)$ are code words which represent the length and "colour" of the runs a_0a_1 and a_1a_2 respectively and are taken from the appropriate white or black run-length code tables (Tables 2/T.b and 3/T.b).

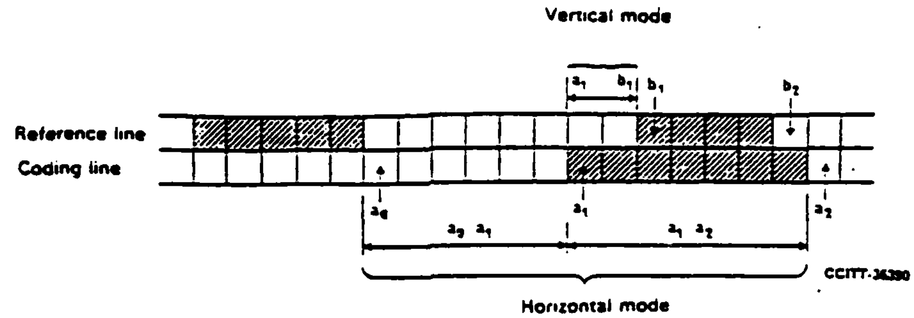


FIGURE 4/T.b - Vertical mode and Horizontal mode

2.2.4 Coding procedure

The coding procedure identifies the coding mode that is to be uesd to code each changing element along the coding line. When one of the three coding modes has been identified according to Step 1 or Step 2 mentioned below, an appropriate code word is selected from the code table given in Table 1/T.b. The coding procedure is as shown in the flow diagram of Figure 5/T.b.

Step 1

i) If a pass mode is identified, this is coded using the word 0001 (Table 1/T.b). After this processing, picture element a_0 just under b_2 is regarded as the new starting picture element a_0 for the next coding. (see Figure 2/T.b)

ii) If a pass mode is not detected, then proceed to step 2.

Note -- It does not affect compatibility to restrict the use of pass mode in the encoder to a single pass mode. Variations of the algorithm which do not affect compatibility should be the subject of further study.

Step 2

i) Determine the absolute value of the relative distance a_1b_1.

ii) If $|a_1b_1| \leq 3$, as shown in Table 1/T.b, a_1b_1 is coded by the vertical mode, after which position a is regarded as the new starting picture element a for the next coding.

iii) If $|a_1b_1| > 3$, as shown in Table 1/T.b, following horizontal mode code 001, a_0a_1 and a_1a_2 are respectively coded by one-dimensional run length coding.
Run lengths in the range of 0 to 63 pels are encoded with their appropriate Terminating code word of Table 2/T.b. Note that there is a different list of code words for black and white run lengths. Run lengths in the range of 64 to 2623 pels are encoded first by the Make-up code word representing the run length which is nearest, not longer, to that required. This is then followed by the Terminating code word representing the difference between the required run length and the run length represented by the Make-up code. Run lengths in the range of longer than or equal to 2624 pels are coded first by the Make-up code of 2560. If the remaining part of the run (after the first Make-up code of 2560) is 2560 pel or greater, additional Make-up code(s) of 2560 are issued until the remaining part of the run becomes less than 2560 pels. Then the remaining part of the run is encoded by Terminating code or by Make-up code plus Terminating code according to the range as mentioned above.

After this processing, position a_2 is regarded as the new starting picture element a_0 for the next coding.

Note — Coding examples are referred to Section 4.2.5 in Recommendation T.4.

TABLE 1/T.b - Code Table

Mode	Elements to be coded		Notation	Code word
Pass	b_1, b_2		P	0001
Horizontal	a_0a_1, a_1a_2		H	001 + $M(a_0a_1)$ + $M(a_1a_2)$ (see Note 1)
Vertical	a_1 just under b_1	$a_1b_1 = 0$	V(0)	1
	a_1 to the right of b_1	$a_1b_1 = 1$	$V_R(1)$	011
		$a_1b_1 = 2$	$V_R(2)$	000011
		$a_1b_1 = 3$	$V_R(3)$	0000011
	a_1 to the left of b_1	$a_1b_1 = 1$	$V_L(1)$	010
		$a_1b_1 = 2$	$V_L(2)$	000010
		$a_1b_1 = 3$	$V_L(3)$	0000010
Extension				0000001xxx

Note 1— Code M( ) of the horizontal mode represents the code words in Table 2/T.b and 3/T.b

TABLE 2/T.b

Terminating codes

White run length	Code word	Black run length	Code word
0	00110101	0	0000110111
1	000111	1	010
2	0111	2	11
3	1000	3	10
4	1011	4	011
5	1100	5	0011
6	1110	6	0010
7	1111	7	00011
8	10011	8	000101
9	10100	9	000100
10	00111	10	0000100
11	01000	11	0000101
12	001000	12	0000111
13	000011	13	00000100
14	110100	14	00000111
15	110101	15	000011000
16	101010	16	0000010111
17	101011	17	0000011000
18	0100111	18	0000001000
19	0001100	19	00001100111
20	0001000	20	00001101000
21	0010111	21	00001101100
22	0000011	22	00000110111
23	0000100	23	00000101000
24	0101000	24	00000010111
25	0101011	25	00000011000
26	0010011	26	000011001010
27	0100100	27	000011001011
28	0011000	28	000011001100
29	00000010	29	000011001101
30	00000011	30	000001101000
31	00011010	31	000001101001
32	00011011	32	000001101010
33	00010010	33	000001101011
34	00010011	34	000011010010
35	00010100	35	000011010011
36	00010101	36	000011010100
37	00010110	37	000011010101
38	00010111	38	000011010110
39	00101000	39	000011010111
40	00101001	40	000001101100
41	00101010	41	000001101101
42	00101011	42	000011011010
43	00101100	43	000011011011
44	00101101	44	000001010100
45	00000100	45	000001010101
46	00000101	46	000001010110
47	00001010	47	000001010111
48	00001011	48	000001100100
49	01010010	49	000001100101
50	01010011	50	000001010010
51	01010100	51	000001010011
52	01010101	52	000000100100
53	00100100	53	000000110111
54	00100101	54	000000111000
55	01011000	55	000000100111
56	01011001	56	000000101000
57	01011010	57	000001011000
58	01011011	58	000001011001
59	01001010	59	000000101011
60	01001011	60	000000101100
61	00110010	61	000001011010
62	00110011	62	000001100110
63	00110100	63	000001100111

TABLE 3/T.b - Make-up codes between 64 and 1728

White run lengths	Code word	Black run lengths	Code word
64	11011	64	0000001111
128	10010	128	000011001000
192	010111	192	000011001001
256	0110111	256	000001011011
320	00110110	320	000000110011
384	00110111	384	000000110100
448	01100100	448	000000110101
512	01100101	512	0000001101100
576	01101000	576	0000001101101
640	01100111	640	0000001001010
704	011001100	704	0000001001011
768	011001101	768	0000001001100
832	011010010	832	0000001001101
896	011010011	896	0000001110010
960	011010100	960	0000001110011
1024	011010101	1024	0000001110100
1088	011010110	1088	0000001110101
1152	011010111	1152	0000001110110
1216	011011000	1216	0000001110111
1280	011011001	1280	0000001010010
1344	011011010	1344	0000001010011
1408	011011011	1408	0000001010100
1472	010011000	1472	0000001010101
1536	010011001	1536	0000001011010
1600	010011010	1600	0000001011011
1664	011000	1664	0000001100100
1728	010011011	1728	0000001100101

Make-up codes between 1792 and 2560

Run length (black and white)	Make-up codes
1792	00000001000
1856	00000001100
1920	00000001101
1984	000000010010
2048	000000010011
2112	000000010100
2176	000000010101
2240	000000010110
2304	000000010111
2368	000000011100
2432	000000011101
2496	000000011110
2560	000000011111

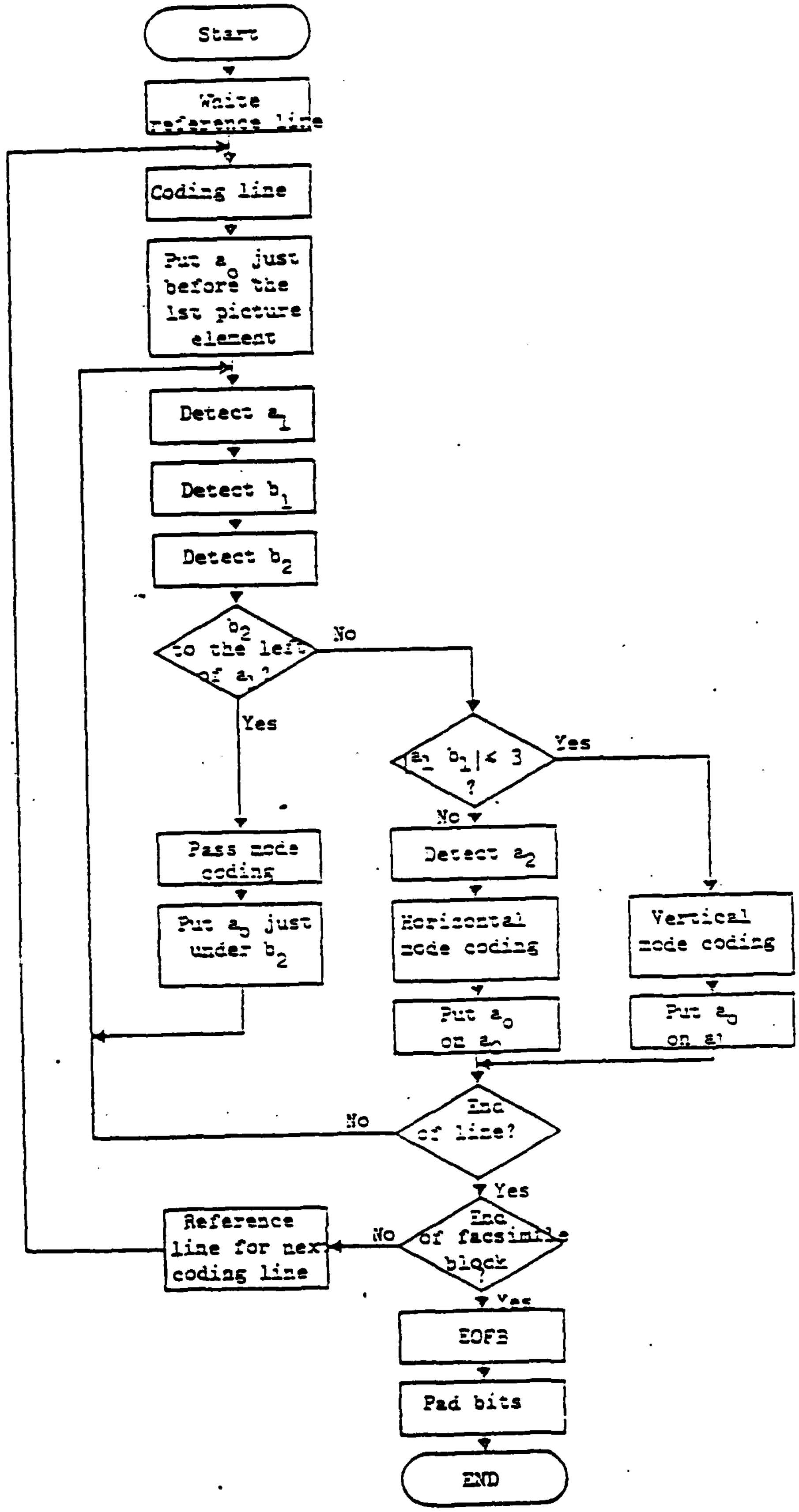


FIGURE 5/T.b - Coding flow diagram

2.2.5 Processing the first and last picture element in a line

a) Processing the first picture element

The first starting picture element a on each coding line is imaginarily set a position just before the first picture element, and is regarded as a white picture element (see Section 2.2.2)
The first run length on a line a a is replaced by a a - 1. Therefore, if the first actual run is black and is deemed to be coded by horizontal mode coding, then the first code word M(a a) corresponds to a imaginary white run of zero length (see Figure 10/T.4 in Recommendation T.4 Example 5)

b) Processing the last picture element

The coding of the coding line continues until the position of the imaginary changing element situated just after the last actual element has been coded. This may be coded as a or a . Also, if b and /or b are not detected at any time during the coding of the line, they are positioned on the imaginary changing element situated just after the last actual picture element on the reference line.

2.3 Optional facsimile coding schemes for black and white images

2.3.1 Uncompressed mc_e

Uncompressed mode is an optional coding scheme associated to basic facsimile coding scheme and is used to transmit the image information without data compression technique as shown in Table 4 /T.b.

Extension code in section 2.2.4 with the xxx bit set to 111 is used as an entrance code from basic coding scheme in Section 2.2 to uncompressed mode.

TABLE 4/T.b - Uncompressed mode code words

Entrance code to uncompressed mode	Bacic coding scheme : 0000001111	
	Image pattern	*Code word*
Uncompressed mode code	1 01 001 0001 00001 00000	1 01 001 0001 00001 000001
Exist from uncompressed mode code	0 00 000 0000	0000001T 00000001T 000000001T 0000000001T 00000000001T

T denotes a tag bit which tells the colour of the next run (black=1, white=0)

2.4. Facsimile coding control functions

2.4.1 Control functions for basic facsimile coding scheme

2.4.1.1 End of facsimile block

The End of facsimile block code is added to the end of every coded facsimile block. The format of EOFB is as follows:

$$\text{Format: } \underbrace{000000000001000000000001}_{\text{24 bits}}$$

2.4.1.2 Pad bits

Pad bits may be used after the End of facsimile block code if it is necessary to align on octet boundaries or to a fixed block size. The format used is as follows.

Format : Variable length string of 0s.

2.4.1.3 Extension

Extension code is used to indicate the change from the current mode to another mode, e.g., another coding scheme.

Format : 0000001xxx

Where xxx = 111 indicates uncompressed mode which is specified in Section 2.3.1.

Further study is needed to define other unspecified xxx bit assignments and their use for any further extensions.

3. Optional grey scale facsimile coding schemes and their coding control functions

For further study

4. Optional colour facsimile coding schemes and their coding control functions

For further study

Table 1 Difference between Group 3 two-dimensional coding scheme and Group 4 basic coding scheme

ITEM / APPARATUS	First line	K parameter	Line synchronization code word	End of page	Fill bits per line	Pad bits per page	Run length longer than 2623
G3	one-dimensional coding (MH)	K=2 (standard Res.) K=4 (optional higher Res.)	EOL+tag	RTC =6×(EOL + tag)	variable length string of "0"s	Not specified	Not specified
G4	two-dimensional coding (MR) Note : reference line for first coded line is set to an imaginary white line	K : not specified all lines including the first line of a page are coded two -dimensionally	Not required	EOFB =2×EOL	Not required	variable length string of "0"s	Using the MUC (s) of 2560

APPENDIX C

EXPECTED NUMBER OF STUFFING BITS

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Expected Number Of Stuffing Bits

A binary message of length L bits is assumed to be random. A sync pattern of N consecutive 1's must be avoided in the data stream. Therefore, whenever N-1 consecutive 1's are observed by the transmitter, a Ø is stuffed after them to avoid the possibility of false sync. In order for a Ø bit to be stuffed at a given location, the previous N-1 bits must be ones, and the bit before that must be Ø or the N-1 previous bits must be 1 and the bit before that must be Ø or etc. Therefore the probability of a stuffing bit at a given location is:

$$P_{BS} = \frac{1}{2^{N-1}}\left\{\frac{1}{2} + \frac{1}{2^{N-1}}\left[\frac{1}{2} + \frac{1}{2^{N-1}}\left(\frac{1}{2} + \frac{1}{2^{N-1}}\cdots\right)\right]\right\}$$

$$= \frac{1}{2^N} + \frac{1}{2^{2N-1}} + \frac{1}{2^{3N-2}} + \frac{1}{2^{4n-3}} + \cdots$$

$$= \frac{1}{2^N}\left[1 + \frac{1}{2^{N-1}} + \frac{1}{2^{2N-2}} + \frac{1}{2^{3N-3}} + \cdots\right]$$

$$= \frac{1}{2^N}\left[\frac{1}{(2^{N-1})^0} + \frac{1}{(2^{N-1})^1} + \frac{1}{(2^{N-1})^2} + \frac{1}{(2^{N-1})^3} + \cdots\right.$$

$$P_{BS} = \frac{1}{2^N}\cdot\frac{1}{(1-2^{-N+1})} = \frac{1}{2^N-2}$$

Therefore the expected number of bits stuffed, if L>>N, is:

$$L\,P_{BS} = \frac{L}{2^N - 2}$$

For X.25, N=6, so:

$$L\,P_{BS} = \frac{L}{2^6 - 2} = \frac{L}{62}$$

APPENDIX D

DERIVATION OF EXPECTED HALT TIME

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Derivation of Expected Halt Time

The expected halt time, H, is given by:

$$H=\sigma F(w)$$

where

$$F(w)=\int_w^{\infty}(t-w)p(t)\,dt$$

p(t) is the standardized normal density function:

$$p(t)=(2\pi)^{-1/2}\exp\left(-\frac{t^2}{2}\right)$$

Now:

$$F(w)=\int_w^{\infty}tp(t)dt - w\int_w^{\infty}p(t)dt$$

$$=(2\pi)^{-1/2}\int_w^{\infty}t\exp\left(-\frac{t^2}{2}\right)dt - wQ(w)$$

where Q(w) is the tabulated function:

$$Q(w)=1-P(w)=\int_w^{\infty}p(t)dt$$

Then using $u^2=\frac{t^2}{2}$, we obtain:

$$F(w)=(2\pi)^{-1/2}\exp\left(-\frac{w^2}{2}\right) - wQ(w)=p(w)-wQ(w)$$

END

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